INDICATORS
for Assessing Environmental Performance of
WATERSHEDS
IN SOUTHERN ALBERTA

Alberta
Environment

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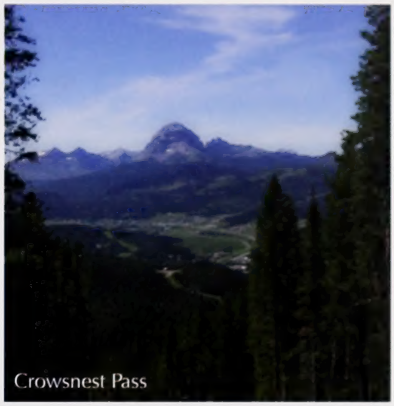
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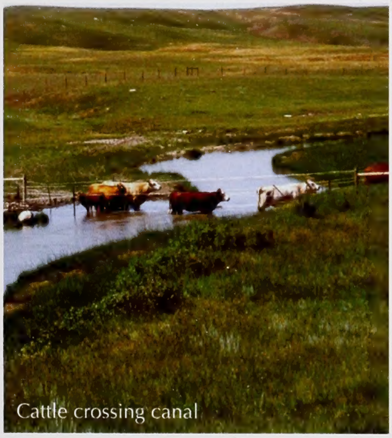
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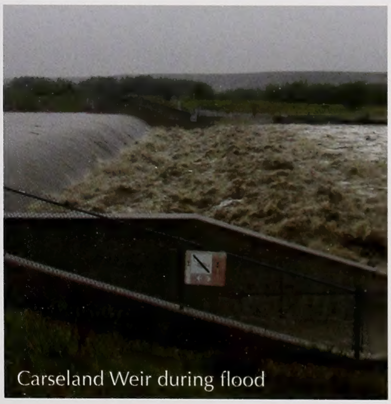
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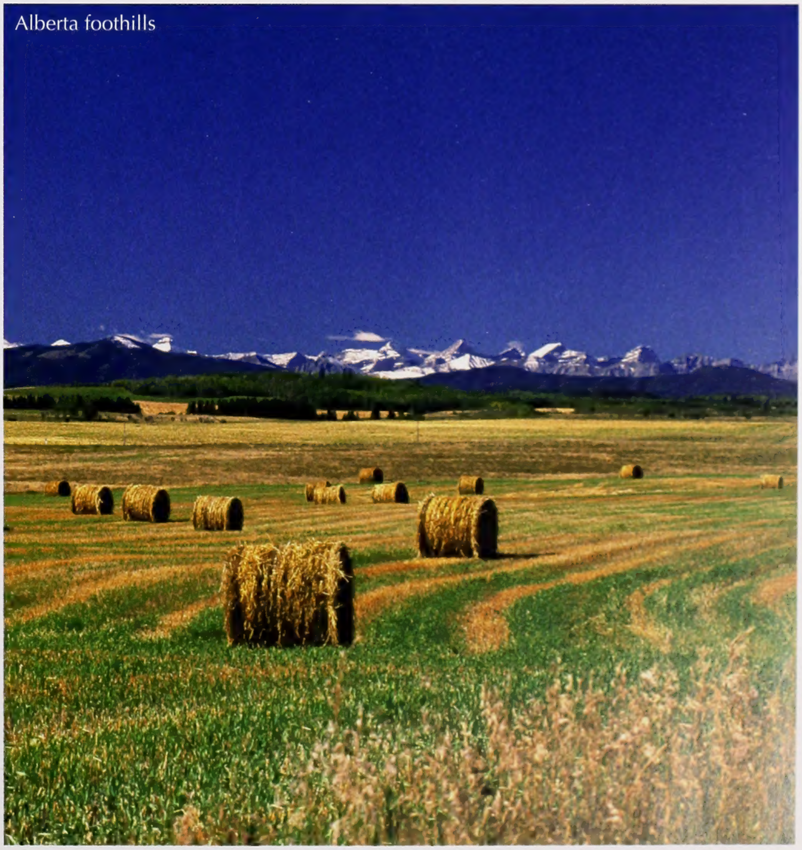
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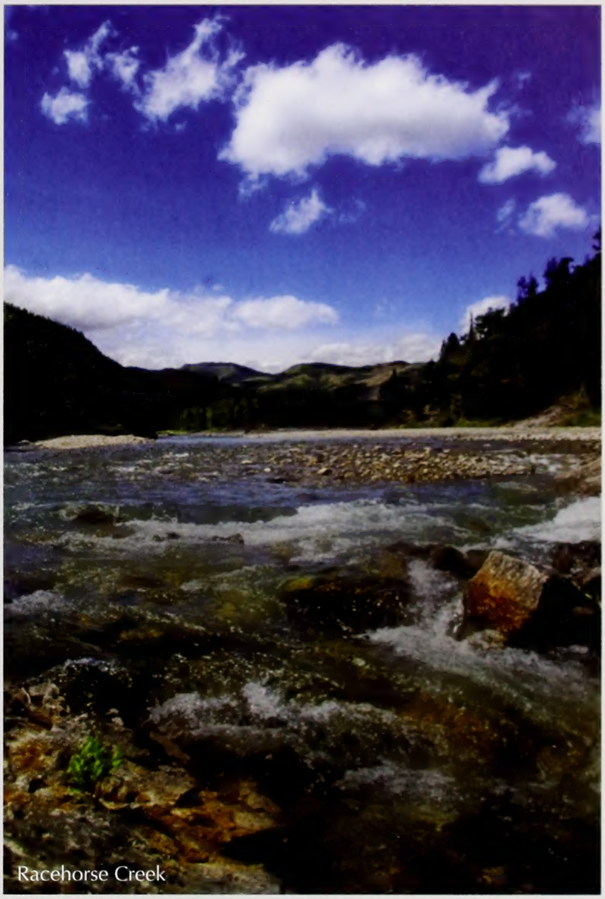
Executive Summary

Outcomes are conditions or functions environmental users and managers would like from the environment, and they should be selected by the Watershed Planning and Advisory Councils (WPACs) and Watershed Stewardship Groups (WSGs). The three provincial outcomes defined in Alberta's *Water for Life* strategy (AENV 2003) as well as the various uses of water throughout watersheds should set the context for these watershed-specific outcomes. The provincial outcomes are:

- safe, secure drinking water supply
- reliable, quality water supplies for a sustainable economy
- healthy aquatic ecosystems

To manage environmental performance of watersheds, a five-step adaptive system should be implemented involving (i) defining environmental outcomes, (ii) selecting condition and pressure indicators, (iii) monitoring indicators, (iv) evaluating outcomes using targets and thresholds, and (v) implementing management actions (see Figure 3, section 1.2). Variation in land use and intensity of use across the river basins in southern Alberta should be considered when outcomes, thresholds, and targets are selected. In headwater reaches outcomes may focus on healthy coldwater aquatic ecosystems, while further downstream water requirements for human uses are likely to become more important as priorities shift. Reach-specific thresholds and targets will be needed that represent socially, economically, and scientifically acceptable compromises between the various human uses of water and the protection and restoration of healthy aquatic and riparian ecosystems.

This report identifies generic condition and pressure indicators for land, water quantity, water quality, and aquatic and riparian ecosystems and explains how these indicators are linked to environmental outcomes. The land base of watersheds acts as a catchment for precipitation, and whatever occurs on this land base ultimately affects the quantity and quality of surface water running off the land into the streams, rivers, and lakes as well as the underlying groundwater. Four land quality condition indicators are proposed to measure the ability of the land to perform its basic water-related functions. Two of the indicators, the amount of land in watersheds covered by natural cover types and model-predicted soil erosion rates, are measured or estimated over entire watersheds and do not involve on-the-ground surveys. Two other land quality condition indicators are based on site-specific



Racehorse Creek

measurements of rangeland and riparian health. Three land use pressure indicators are also proposed:

- human-altered land types and constructed landscape features
- human population and dwelling unit density
- amount of agricultural and non-agricultural fertilizers and pesticides applied to the land

Human footprint, population, and dwelling unit density should be reported separately for the area of watersheds within a set distance of waterbodies (e.g., 500 m), because land use activities can have a greater impact in these areas.

The health of entire river ecosystems, including water quality, benthic invertebrates, fish, and riparian vegetation, depends on natural variability in the quantity and timing of flows. The water quantity condition indicators proposed here are simply the overall deviation of recorded flows from naturalized flows and various flow


Southern Alberta wetland area

regime benchmarks set by environmental managers and scientists. Two water quantity pressure indicators are also recommended. One is the changes to annual runoff rates and volumes and the magnitude and frequency of base and peak flow events in subwatersheds where the natural vegetation has been altered, impacting surface runoff patterns. The other pressure indicator is the actual amount of water being removed from and returned to streams and rivers as a result of licensed water diversions. This is critical information for achieving targets for water conservation, efficiency, and productivity.

Water quality cumulatively reflects all natural and human activities occurring in a watershed and can respond to changes in these activities more quickly than aquatic biological indicators. The condition indicators that are proposed are natural parameters associated with widespread water quality concerns in southern Alberta: total suspended solids, nutrients, dissolved oxygen, temperature, and pathogens. These same natural parameters are also proposed as water quality pressure indicators, but measurements are taken from effluent released by point sources such as municipal and industrial wastewater facilities. Loadings can then be evaluated to determine the individual and cumulative effects of point sources, relative to non-point sources, on ambient water quality.

Biological indicators are also important because they provide a cumulative assessment of environmental performance by integrating over the long-term the effects of all sources of environmental pressure involving land use and changes to water quantity and quality. Two indicators of aquatic and riparian ecosystem health are proposed here: measurements of individual indicator species (e.g., presence/absence, abundance, distribution) and integrated multi-species measures of diversity within biological communities.

Although some of the proposed indicators are already being monitored, many are not, and the WPACs and WSGs will need to develop integrated monitoring programs that will provide accurate assessments at the watershed scale. Work should begin at the larger spatial scales of assessment relying on existing data and remote or areal sampling before progressing to finer scales where field-based stratified regional surveys will be required to sample small scale variables. On-the-ground surveys will require a random sampling approach if accurate estimates are to be obtained of the condition of land, ambient water quality, and aquatic and riparian ecosystem health across entire watersheds.

Using the environmental performance management system and indicators proposed in this report, the WPACs and WSGs have the opportunity to address the overall lack of coordination in managing from a watershed perspective by linking values or trends they observed in the water quantity, water quality, and aquatic and riparian ecosystem indicators they monitor to corresponding patterns observed in land use and land quality. Based on relationships they observe, they can then make specific recommendations to both municipal and provincial agencies to address priority issues.

1.0 Introduction

1.1 Context

The land base of watersheds acts as a catchment for precipitation, and whatever occurs on this land base ultimately affects the quantity and quality of surface water running off the land into the streams, rivers, and lakes draining the watershed as well as the underlying groundwater. Stream and river systems draining watersheds all have flow regimes that include high flows during runoff events as well as low flows during drier periods in the summer and winter (Figure 1). Flow regimes also differ from year to year, because some years will have more precipitation than others (Figure 1). The health of entire river ecosystems depends on this natural variation in flow, because aquatic and riparian communities have become adapted to this variation. Natural variation in flows with high and low-flow periods is critical for maintaining physical habitat for these communities and providing adequate water quality for aquatic life as well as human uses. Human alteration of the natural flow regime can occur directly and indirectly. On large streams and rivers,

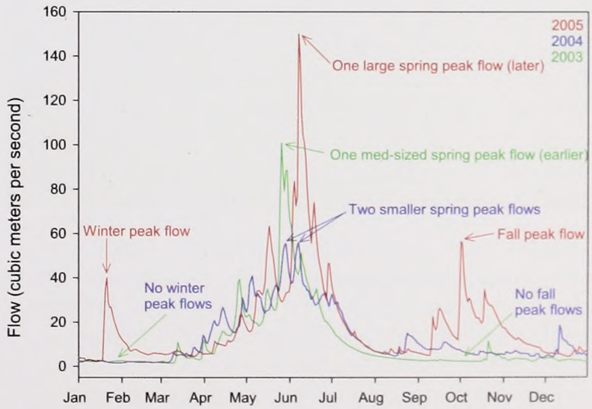
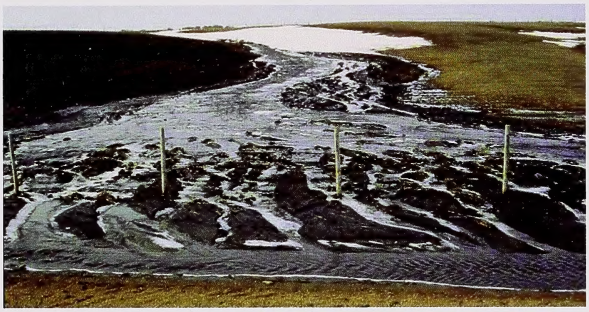


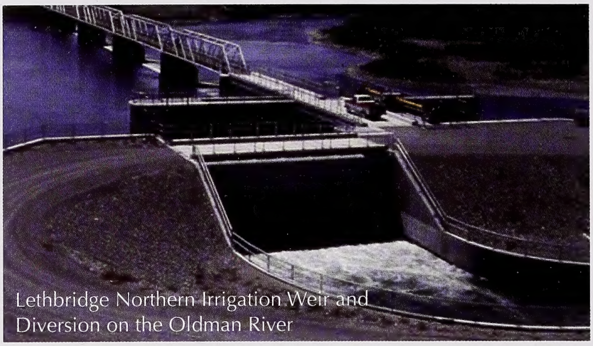
Figure 1. Flow regimes measured on the Castle River (in the headwaters of the Oldman River basin, WSC Station ID #05AA022) near Beaver Mines in 2003, 2004, and 2005.

dams and diversions are the main contributing factors altering the natural flow regime. However, on smaller tributaries, changes to land cover are the primary factors altering the natural flow regime. Land use activities such as forestry and agriculture that alter native vegetation land cover and urbanisation that involves constructing large areas of impervious surfaces as well as natural disturbances such as forest fires and avalanches can all affect flow regimes in small streams. Runoff volume can increase and groundwater levels can be diminished when the natural vegetation is removed, the soil is compacted, and impervious surfaces are constructed, because these activities affect interception of precipitation and infiltration into the ground.



WATER QUALITY CAN BE DEGRADED BY NON-POINT AND POINT SOURCES.

Degradation of water quality can arise from widespread non-point sources of contaminants such as precipitation or dust from the air, surface runoff from the land, sediments on river and lake bottoms, and groundwater seepage. Using fossil fuels, burning forests, and agricultural and industrial activities are all ways contaminants can be released to the atmosphere that can in turn affect water quality. Land use activities that expose bare soil, erode banks, or release pollutants directly onto the land surface decrease the quality of runoff and surface water. These activities can also affect groundwater quality. Besides non-point sources, contaminants can also enter a watershed from specific points such as municipal wastewater treatment plants, stormwater outfalls, or industrial facilities where effluent is released to waterbodies.



Lethbridge Northern Irrigation Weir and Diversion on the Oldman River

STREAM AND RIVER CROSSINGS CAN AFFECT WATER QUANTITY AND QUALITY, AQUATIC AND RIPARIAN ECOSYSTEM HEALTH, AND ANIMAL MOVEMENT CORRIDORS.

Beyond the direct effects of human land uses on water quantity and quality and the associated impacts on aquatic and riparian ecosystem health, land use features that cross streams and rivers such as roads and dams can directly affect aquatic biodiversity by dividing continuous waterways used as corridors for movement into separate, isolated fragments. This in turn can lead to changes in species composition, abundance, and distribution.

Given these effects of human activities on the overall environmental condition of watersheds, a system is needed to manage the impacts and ensure a desired level of environmental performance is achieved for our watersheds. Environmental management involves managing how humans interact with and impact the environment. Its goal is not necessarily to conserve or restore a pristine environmental state, but rather to make use of environmental resources in a sustainable fashion allowing for continued, long-term use. Environmental management seeks to understand how human activities affect environmental conditions and reach agreement amongst users on acceptable tradeoffs between the amount of environmental degradation and intensity of environmental use. As part of this process, Watershed Planning and Advisory Councils (WPACs) and Watershed Stewardship Groups (WSGs) provide forums for all watershed users and managers to work together to develop holistic watershed management plans that can guide them as they make decisions that will affect how their watersheds will look in the future.

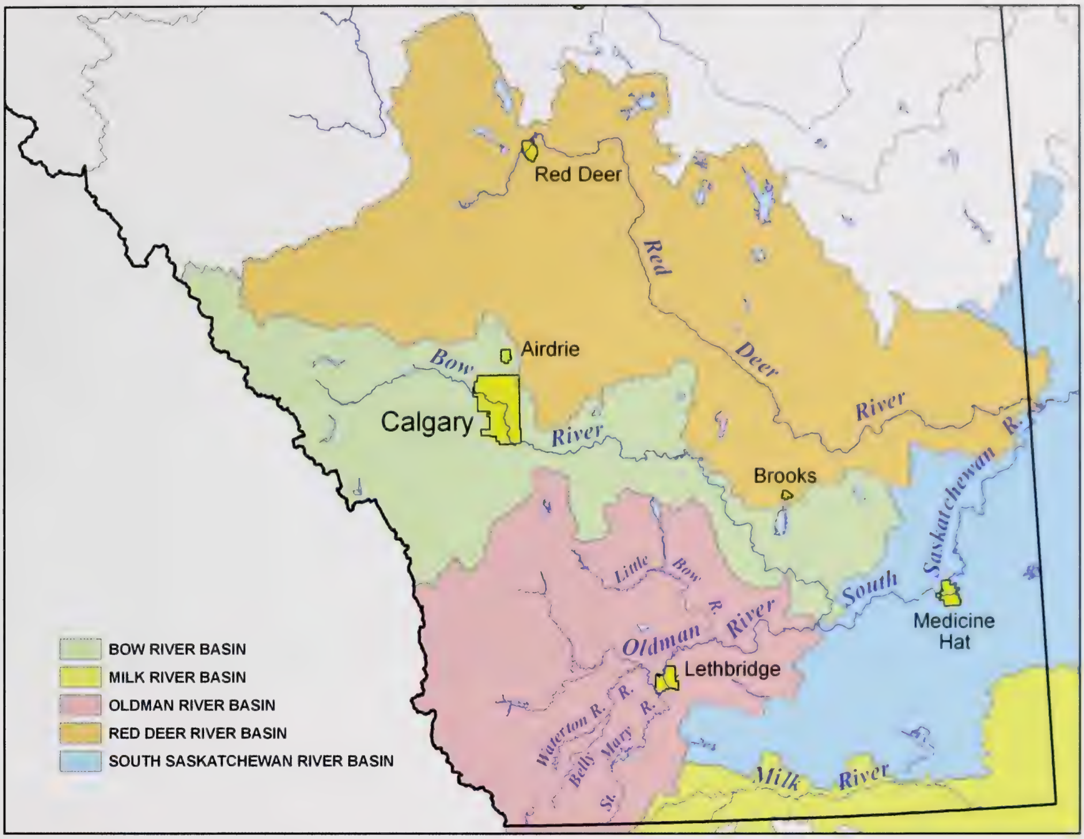


Figure 2. Map of the five major southern Alberta river basins.

This report on environmental indicators is meant to act as an initial attempt to suggest what should be measured to monitor the environmental state of watersheds in southern Alberta (Figure 2) and work towards achieving the desired outcomes for these watersheds using an adaptive environmental performance management system. ***The intended audience of this report is all of the management agencies and stakeholders taking an active role in the WPACs and WSGs of southern Alberta, and the goal is to identify the environmental features or elements that are most relevant to the common environmental issues facing the region.*** Generic environmental indicators have been identified in four areas where there is increasing pressure on the environment. These are land, water quantity, water quality, and aquatic and riparian ecosystem health. Air quality is also a major concern that should be considered because of the overriding effects of emissions on the climate and contaminant levels of entire watershed ecosystems; however, because it is not contained within discrete watershed boundaries it is not addressed in this introductory document. At this time the indicators presented are individual measurements such as stream crossing density or dissolved oxygen and are not synthesized into an overall measure of environmental condition. The report will explain what features or elements could be monitored and how these environmental indicators are linked to environmental outcomes. The suggested indicators could form the basis for the environmental performance management system to be implemented by the WPACs and WSGs, and the indicators could become an integral part of State of the Watershed reporting and Integrated Watershed Management Planning.

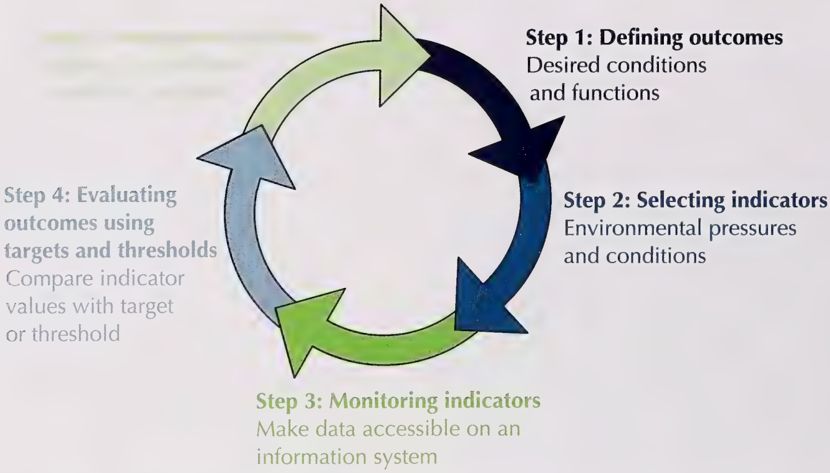


Figure 3. Adaptive Management: Five steps involved in managing environmental performance.

1.2 Managing environmental performance

The basis for the use of the environmental indicators proposed in this report is to measure and monitor watershed conditions as part of an adaptive environmental performance management system. This system informs managers and the public about the condition of a watershed relative to what is desired and whether or not the actions being taken to manage environmental impacts are actually working.

The process of managing environmental performance can be broken down into five steps, of which determining appropriate environmental indicators is just one (Figure 3).

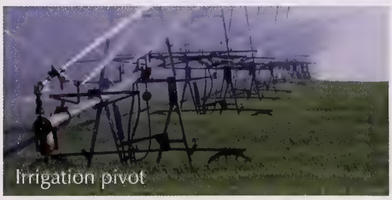
1.2.1 Step 1: Defining environmental outcomes

The first step involves defining environmental outcomes or what a watershed should look like. ***Outcomes are specific conditions or functions that environmental users and managers would like from the environment (Edvardsson 2007).*** Alberta's *Water for Life* strategy (AENV 2003) has defined three environmental outcomes for the province as a whole. These are:

- safe, secure drinking water supply
- reliable, quality water supplies for a sustainable economy
- healthy aquatic ecosystems

Although priority concerns differ across watersheds, the WPACs and WSGs should ensure all their activities are in sync with these provincial outcomes. In order for them to be able to reach the *Water for Life* outcomes they will need to set more specific, but related, outcomes that reflect local issues. These outcomes should be based on the various uses of water through their watershed and take into account uses of water in the associated downstream watersheds. Ultimately, WPACs and WSGs may set a few broad outcomes for their watershed or sub-watershed as a whole, and then set a series of reach-specific thresholds and targets (see section 2.2.4) for the indicators they have selected, because environmental issues and problems change with distance downstream (e.g., Bow Basin Watershed Management Plan, BRBC 2007). These thresholds and targets will need to represent socially, economically, and scientifically acceptable compromises between the various human uses of water (irrigation, stock watering, recreation, commercial and industrial processing, drinking water) and the protection and restoration of healthy aquatic and riparian ecosystems.

Variation in soil and land cover types as well as types of land use and intensity of use across the river basins in southern Alberta (see satellite image) should be considered when outcomes, thresholds, and targets are selected and defined, because these factors will determine what is realistically achievable in terms of water quantity, water quality, and aquatic and riparian ecosystem health across different parts of the basins. Outcomes in the headwater reaches of the mainstem rivers and their tributaries in the Forestry Reserve could focus on healthy coldwater


Irrigation pivot


Drinking water


Healthy aquatic ecosystem

aquatic ecosystems. However, priorities shift outside of the Forestry Reserve where land use intensity increases and water quantity and quality requirements for human uses become more important. One outcome in this region may be to maintain flow regimes that will adequately assimilate municipal and industrial wastewater effluent and support healthy riparian areas to buffer the effects of land use. Another outcome might be that land use intensities do not jeopardize human uses of water related to consumption, irrigation of crops, industrial processing, and recreation.

1.2.2 Step 2: Selecting environmental indicators

Once environmental outcomes have been defined, environmental indicators need to be selected so it is possible to measure whether or not the outcomes are being reached. Since outcomes are complex, multiple indicators may be needed to reflect the overall state of each outcome. ***Indicators are specific physical, chemical, and biological attributes or components of the environment that play an important role in affecting environmental outcomes. Indicators are always part of the cause-and-effect relationship between human activities on the landscape and the environmental response to those activities.*** Therefore, there must be a quantifiable linkage between each environmental indicator assigned to an outcome and the state of that outcome.

When selecting environmental indicators, both condition and pressure indicators should be considered. ***Condition indicators measure biotic or abiotic characteristics in the environment,*** such as soil erosion rates, the difference between recorded and naturalized flows, the concentration of total suspended solids in a waterbody, or the diversity of benthic invertebrates. Measuring condition indicators can provide an estimate of the quality of environmental resources with respect to human or ecological requirements. ***Pressure indicators, on the other hand, measure human activities*** like human land cover


Water sampling

types, pesticide application rates, water use by the various sectors, or wastewater effluent loadings. These are activities that can affect important resources in the environment when their intensity or magnitude reaches a certain point.

1.2.3 Step 3: Monitoring environmental indicators

Once indicators are selected, the third step in the adaptive environmental performance management system is to monitor these indicators. Without a quantitative understanding of key pressures and the effects on watershed conditions, it is impossible to make wise management decisions.

1.2.4 Step 4: Evaluating outcomes using targets and thresholds

Monitoring results may be of little use in directing management actions, without quantitatively defining desired conditions for the indicators being monitored. Desired conditions are defined in terms of targets or threshold values. This process is the fourth step in the adaptive environmental performance management system. ***A threshold is the value of an indicator that reflects a problem condition, while a target is a value that reflects a desirable outcome.*** Thresholds and target values must be decided on by the individual WPACs and WSGs, because they need to be reach or watershed-specific so they are relevant to local conditions and are realistically achievable. Although water quality guidelines have been set at the provincial level and various water quantity thresholds and targets have been proposed or implemented in southern Alberta, these guidelines may not be broadly appropriate for particular reaches of a stream or river. Furthermore, no provincial guidelines exist for land use and aquatic and riparian ecosystem health. The WPACs and WSGs will need to build consensus amongst their stakeholders as to what threshold and target values they are willing to adopt, and this may involve compromises. For some indicators, appropriate threshold and target values will be available from other jurisdictions, while for others modelling will be required to determine site-specific values. In cases where such values are not available, interim values will simply need to be set based on professional judgment and what can be reasonably implemented. In an adaptive management system, threshold and target values can be adjusted as environmental conditions change or the processes involved become better understood.

1.2.5 Step 5: Management action

The final step in the continuous process of managing environmental performance is to implement management actions based on where indicator values lie with respect to thresholds and targets. If the indicator is within the range of desired conditions, the management actions being used


Coulees


Wildlife in riparian area

should continue. However, if the indicator is approaching or outside of the range of desired conditions, actions should be taken to address the problem. Depending on the particular problem identified, corrective management actions could involve any or all of:

- changes in regulations or policies controlling what activities are permissible and requiring certain actions to be taken to monitor environmental impacts
- implementation of economic instruments to incent the use of beneficial management practices or behaviours

1.3 Summary

This report is an initial attempt to suggest a generic set of environmental indicators for monitoring the state of watersheds in southern Alberta. The intended audience is all of the management agencies and stakeholders taking an active role in the WPACs and WSGs of southern Alberta. The indicators presented are raw measurements of features or elements of the environment and not higher-level indices, because these will be more relevant to the specific environmental problems facing this region than higher-level indices. Indicators are considered for four areas of the environment: land, water quantity, water quality, and aquatic and riparian ecosystem health.

2.0 Generic Environmental Indicators

The specific outcomes the WPACs and WSGs decide to work towards should determine which indicators they use to monitor progress towards reaching the environmental conditions or functions these outcomes define. Because there are already three provincial outcomes associated with the *Water for Life* strategy (AENV 2003), this report proposes a set of generic environmental indicators for land, water quantity, water quality, and aquatic and riparian ecosystem health that are linked to these outcomes. Many of these proposed indicators will be relevant to the more specific outcomes chosen by WPACs and WSGs throughout southern Alberta.

2.1 Land

Land quality can be considered as the condition of the land relative to what is needed to meet water quantity and quality requirements for human uses and to protect aquatic and riparian ecosystem health (see Dumanski and Pieri 2000, Pieri et al. 1995 for more details on the concept of land quality). Land quality should be measured as the amount of land remaining in a natural state and as the ability of all land in an altered or natural state to perform basic water-related functions such as resisting erosion, filtering runoff, regulating the storage and discharge of runoff, and allowing for groundwater recharge.

Land use, on the other hand, is any human use of land that alters it from its natural state (Sisk 1998). It should be measured as the amount of altered land as well as other aspects of human activity on a watershed land base. Land use activities in watersheds are important because they affect surface and ground water as well as the associated aquatic and riparian ecosystem health. Surface water is affected when land use changes the volume of water running off the land and the amount of material that can contaminate water that this runoff carries (Tong and Chen 2002). Groundwater is affected when land use changes the amount of water infiltrating the surface or introduces contaminants into groundwater (Di et al. 2005, Olson et al. 2005). Land use features that cross streams and rivers like roads and dams can also affect fish and benthic invertebrate populations by increasing or decreasing sediment inputs, by dividing continuous waterways used as corridors for movement into separate, isolated fragments, or by altering the flow regime on which these organisms rely (Haskins and Mayhood 1997).

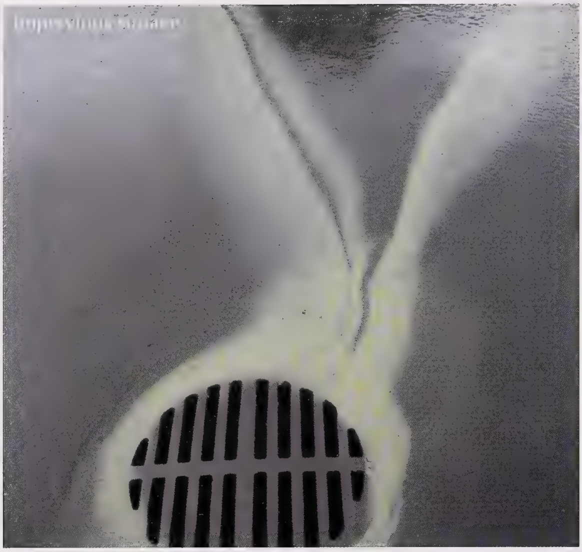
Field Erosion

Runoff is a key factor linking land use to the quantity and quality of surface and ground water. High runoff rates and volumes occurring during periods of snowmelt and storm events can lead to erosion of the land, erosion of stream and river banks, and high loadings of water quality contaminants (Tong and Chen 2002). Soil and land cover types, vegetation surfaces, and land topographies can all

Altered land

Land [illegible] that cross [illegible]

Land remaining in a natural state



affect the rate and volume of runoff as well as its physical, chemical, and biological properties. Bare soils resulting from agriculture or forestry activities can have higher runoff rates and volumes than soils where vegetation is growing, because precipitation is not intercepted by vegetation and the soil surface becomes saturated very quickly so less water infiltrates. Plants, as well as the surface layer of organic material underneath, intercepts and absorbs precipitation and releases it slowly into the ground (LeBlanc et al. 1997). Plants also reduce the amount of runoff by removing water from the soil through evapotranspiration making room for water to infiltrate (LeBlanc et al. 1997). These effects of vegetation are why methods like conservation tillage in agricultural settings and rapid reseeding of disturbed land around construction sites have been developed to avoid creating bare ground. Besides the bare ground associated with many human land uses altering runoff volumes and rates, impervious surfaces such as pavement and buildings increase surface runoff by preventing any water from entering the soil.

Cottonwood community on the lower Red Deer River

Regardless of the cause, increases in runoff generally result in decreases in groundwater infiltration. Clearly, there is a strong relationship between land use and the quantity and quality of surface runoff (Gburek and Folmar 1999), and it is important to implement land management practices that will preserve and restore land covers necessary for more natural runoff and water quality patterns.

Wetlands

Riparian and wetland areas are essential landscape features at the interface between the land and surface waterbodies. In the prairie region of southern Alberta the increased moisture resulting from an elevated riparian water table produces unique plant communities that are drastically different from the surrounding crop and pasture land. As a result, riparian zones support much higher levels of terrestrial biodiversity than the surrounding land. It is estimated that riparian areas support approximately

80% of the fish and wildlife species in southern Alberta in all or part of their life cycle requirements, even though these areas make up only about 2% of the total land base (Chaney et al. 1993). Wildlife use riparian zones for forage and shelter and as movement corridors. Healthy aquatic ecosystems also depend on riparian zones. Nutrient inputs from plant litter can provide the basis for the aquatic food chain. Woody debris provides critical cover for benthic

Riparian buffer, cropped land

No riparian buffer, cropped land

invertebrates and fish. Shade from overhanging vegetation regulates water temperature during the summer. Riparian zones also act as natural biofilters, removing sediments, nutrients, and harmful pathogens from the water running off the land. The deep binding roots of riparian vegetation also play a crucial role in preventing soil erosion by dissipating energy from high flows and wave action. Wetlands are also critical components of the landscape. In addition to performing many of the same functions as riparian areas, they also have the capacity to store water during floods and gradually release this water, sustaining aquatic environments during periods of drought and recharging groundwater levels.

2.1.1 Land condition and pressure indicators

Coulees have higher rates of erosion

Because the focus of this report is on managing environmental performance from a watershed perspective, land indicators including those for riparian and wetland areas should be linked to the water quantity, water quality, and aquatic ecosystem health outcomes already defined in the *Water for Life* strategy (AENV 2003) as well as the specific outcomes the WPACs and WSGs have set to address these broader provincial outcomes (see section 1.2.1). Terrestrial biodiversity is not an aspect of watersheds that is divided by watershed boundaries into discrete units, and therefore, it is not addressed in this introductory document. However, this is an important aspect of environmental performance that should be considered in the future, and some of the land outcomes proposed in this report are relevant to protecting terrestrial biodiversity.

THE LAND QUALITY INDICATORS PROPOSED IN THIS REPORT ARE THE AMOUNT OF LAND THAT REMAINS COVERED BY NATIVE VEGETATION, RATES OF SOIL EROSION, AND MEASURES OF SITE-SPECIFIC RANGELAND AND RIPARIAN QUALITY. THE LAND USE INDICATORS PROPOSED HERE MEASURE A VARIETY OF TYPES OF HUMAN-ALTERED LAND AND CONSTRUCTED LANDSCAPE FEATURES, HUMAN POPULATION AND DWELLING UNIT DENSITY, AND AMOUNTS OF AGRICULTURAL AND NON-AGRICULTURAL FERTILIZERS AND PESTICIDES APPLIED TO THE LAND

The land quality indicators proposed in this report (Table 1) are condition indicators that measure the ability of the land to perform its basic water-related functions of:

- resisting erosion
- filtering runoff
- regulating the storage and discharge of runoff
- allowing for groundwater recharge

These functions support environmental outcomes related to water quantity and quality requirements for human needs as well the maintenance and restoration of aquatic and riparian ecosystem health. The first two land quality condition indicators are measured over entire watersheds and do not involve on-the-ground surveys. One of these indicators is simply the amount of land in watersheds covered by natural cover types including ecologically similar, non-native cover (Table 1). Natural vegetation plays a key role in the water-related functions of land and in general more natural cover in a watershed will result in a more natural flow regime, higher water quality,

and healthier aquatic and riparian ecosystems. Because of the important functions riparian areas and wetlands in particular perform and because impacts on these areas are widespread, the amount of naturally vegetated riparian areas and wetlands and the proportion of the total watershed area they cover should be measured and evaluated separately from the broader landscape of watersheds as a whole. The other land quality condition indicator is model-predicted soil erosion rates for entire watersheds (Table 1). By mapping erosion rates, the location and intensity of various land use types that disturb the soil can be evaluated to determine whether they are occurring in appropriate areas (Jedrych and Martin 2006).

Table 1. Land condition indicators related to the ability of land to perform its basic water-related functions.

Land condition indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Areal amount & delineation of natural vegetation cover types within watersheds, including ecologically similar, non-native cover. 1. Native/natural cover types with the subclass attributes from the Grassland Vegetation Inventory (McNeil et al. 2006): • riparian areas • grasslands • wetlands 2. Native/natural cover types with the subclass attributes from the Alberta Vegetation Inventory (Nesby 1997): • burnt, regenerating & mature forests with age & size class • naturally non-forested vegetated land (other data sources may be available to refine cover type classifications)	Natural vegetation plays a key role in the basic water-related functions land performs & is an essential component of riparian ecosystems, which support aquatic ecosystems. Identifying the areal amount & delineation of land in a near natural state evaluates the ability of the land to support water quantity, water quality, & aquatic & riparian ecosystem health outcomes.	Land remaining in a natural state is a direct response to how land is used & managed.	Thresholds not yet determined, but percent of watershed area that must be covered in natural vegetation could be set using watershed scale soil erosion & runoff models as well as using studies evaluating aquatic & riparian ecosystem health in relation to land use intensity.	Limit further development of areas with natural vegetation based on thresholds or targets.	Measured over entire watersheds by combining existing land cover data from multiple spatial databases (e.g., AVI & GVI).	Should monitor on an ongoing basis as new development occurs & spatial databases are updated.	Spatial land cover is already being collected remotely. Additional costs involve compiling data from multiple sources.
Model-predicted soil erosion rates	Identifying areas in a watershed with high erosion rates indicates areas where existing or proposed land use will likely impact water quantity & quality.	Although land use changes have a direct impact on soil erosion, this process is also naturally affected by topography, type of vegetative cover, type of soil, amount of precipitation, & climatic patterns.	Thresholds not yet determined, but could be set using soil erosion rates that would exist under natural land cover as a benchmark.	Limit types & intensities of land use in areas with naturally high soil erosion rates.	Should be modelled over entire watersheds at a spatial scale relevant to individual land use decisions that are being made.	Baseline modelling can be done & the effects of proposed changes to land use on soil erosion can be modelled as they arise.	Modelling has been completed by Alberta Agriculture & Food for the Agricultural Region of Alberta Soil Inventory Database (AGRISID). Modelling at finer spatial scale likely required.

Damage from Mountain Pine Beetle

Oldman River

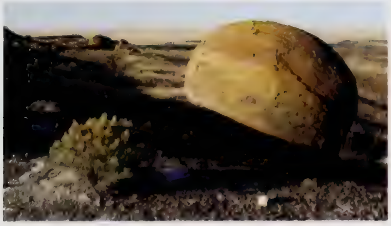


Table 1 continued. Land condition indicators related to the ability of land to perform its basic water-related functions.

Land condition indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Site-specific land quality measurements on public & private rangeland in areas of native grassland, native forest & tame pasture (from Adams et al. 2005) 1. Plant species composition (diversity & richness, see Section 3.5.2 for further details) 2. Presence of plant community structural layers 3. Amount of plant litter 4. Amount of human-caused bare ground	Identifying areas in a watershed where rangeland condition is poor indicates areas where overgrazing may be impacting water quantity & quality & aquatic & riparian ecosystem health.	Although grazing practices have a direct impact on rangeland condition, condition is also affected by natural factors & processes such as soil type, amount of precipitation, wildlife grazing & climatic patterns.	Thresholds not yet determined, but could be set with respect to requirements for land to be able to perform its basic water-related functions of resisting erosion, filtering runoff, regulating the storage & discharge of runoff, & allowing for groundwater recharge.	Overgrazed rangeland can be identified & grazing pressure reduced.	Sampling sites will need to be spread across rangeland areas stratified by vegetation cover type & management practices at densities sufficient to evaluate the condition of these lands at the watershed scale.	Depending on changes in land use & management practices, these indicators should be re-evaluated every 3-7 years.	Alberta Sustainable Resource Development monitors these indicators at a limited number of sites on public rangeland. Costs could be reduced if these assessments became part of the Alberta Biodiversity Monitoring Program.
Site-specific land quality measurements of riparian areas on public & private land (from Fitch et al. 2001) 1. Regeneration of palatable woody riparian species (where applicable, these species may not be supported by small streams) 2. Livestock browse intensity on palatable woody riparian species 3. Amount of riparian area covered in deep binding roots 4. Amount of human-caused bare ground	Identifying areas in a watershed where riparian condition is poor indicates areas where activities such as overgrazing, cropping, recreation, land development, & dams & diversions may be impacting water quantity & quality & aquatic & riparian ecosystem health.	Although land use & dams & diversions can have a direct impact on riparian condition, condition is also affected by natural factors & processes such as natural flows, floods, wildlife grazing, & the ecoregion where the riparian area is being assessed.	Thresholds not yet determined, but could be set with respect to requirements for riparian areas to be able to perform basic water-related functions, as described above. Cows & Fish suggest the lower two levels of their classification system for these measurements are sufficiently unhealthy that they can be considered as below a threshold for a sustainable, functioning riparian ecosystem (Personal Com., N. Ambrose).	Riparian areas in poor condition can be identified & the land use & water diversion pressures being exerted on them can be reduced.	Sampling sites will need to be spread over riparian areas throughout watersheds (i.e., mainstem rivers, tributaries, lakes, & wetlands) so the condition of these areas can be evaluated at the scale of entire watersheds. Sampling will likely be stratified by both the type of riparian area & land use intensity (see Thompson & Hansen 2002).	Depending on changes in land use & management practices, these indicators should be re-evaluated every 3-5 years.	Cows & Fish monitors these indicators on private & public land at the request of land owners & managers. However, sampling sites are not selected randomly at a watershed scale (some projects do involve local level stratification), because of higher costs & the need for landowner permission.


Fescue and mixed grass

The other two land quality condition indicators are site-specific measurements of rangeland (Adams et al. 2005) and riparian (Fitch et al. 2001) health requiring on-the-ground surveys (Table 1). For rangeland health, the proposed measurements are:

- plant species composition
- presence of plant community structural layers (i.e., species varying in size, height, and root depth)
- amount of plant litter (i.e., fresh or decomposing dead material)
- amount of human-caused bare ground


Rough Fescue showing different structural layers of plant community


Human caused bare ground


Plant litter

The species composition of plant communities is important because species associated with mature plant communities are better able to shield the land from solar radiation reducing evaporation and retaining moisture. They also cycle organic material and nutrients more efficiently. Species that colonize recently disturbed land are less able to do these processes and are more vulnerable to invasion by non-native plants. These invasives generally lack the deep, binding root systems that native species have and therefore further increase the potential for erosion and runoff.

The presence of plant community structural layers is also a valuable land quality condition indicator because these layers are reduced as grazing pressure increases. The layers are critical to ability of plants to use sunlight, water, and nutrients from different zones in the vegetation canopy and soil.

The amount of plant litter covering land is another valuable indicator because litter is essential to the functioning of the nutrient and water cycles. It recycles nutrients, slows runoff, reduces soil erosion, and creates a pathway for water to flow into the soil. Finally, human-caused bare ground is an important land quality condition indicator because it is easily eroded by runoff and wind, which can lead to water quality degradation, and because it represents an area where invasive and disturbance-caused plants can easily become established.

A set of site-specific measurements for land quality condition are also proposed as a multi-metric indicator of riparian health (Table 1). These are:

- regeneration of palatable woody riparian species (i.e., woody species grazed by livestock)
- livestock browse intensity on palatable woody riparian species
- amount of riparian area covered in deep binding roots
- amount of human-caused bare ground

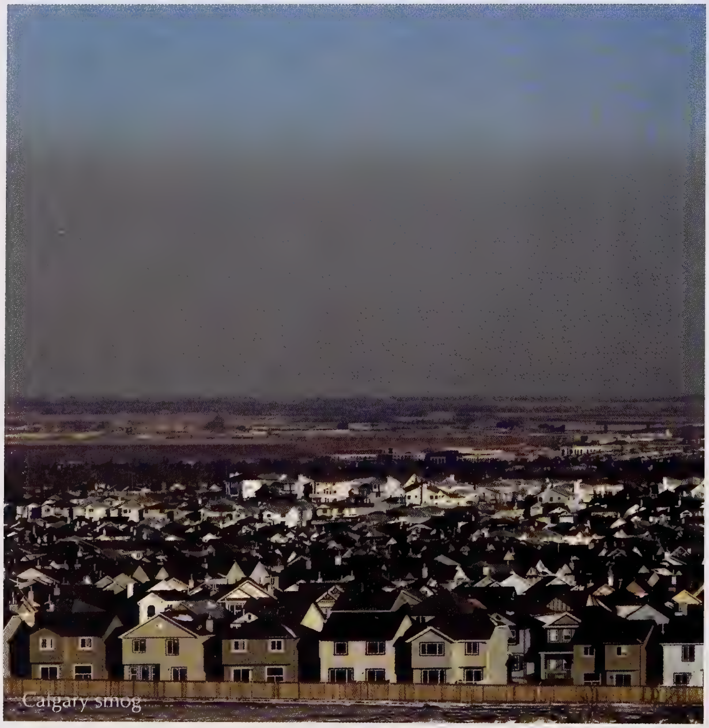
In the prairie region of semi-arid southern Alberta, woody riparian species are trees and shrubs that rely on the shallow riparian water table to survive. It is the palatable species that are relevant indicators because these species can be harmed by livestock using them as food. Some invasive riparian species are also woody, but livestock generally do not feed on these (Fitch et al. 2001). Woody species are important to measure because their roots stabilize the banks of streams and rivers and absorb nutrients in runoff that could otherwise degrade water quality. Having a full range of ages of trees and shrubs present is important so that when older trees and shrubs die younger ones are there to take their place. In order for these species to regenerate and survive they require spring flood events. High flows scour the river banks so there is bare ground suitable for seedling establishment, and provide riparian plants further from the riverbank with moisture (Mahoney and Rood 1998). Woody riparian species also require high flows to subside slowly so that seedlings can grow deep roots and access the riparian water table during the dry summer months (Mahoney and Rood 1998). Together, the important functions woody riparian species perform and the effects of livestock grazing and flow reductions due to dams and diversions make them good indicators. Direct evidence of livestock browse on palatable woody riparian species is also important to measure because this can harm healthy woody plants that are already established and prevent the establishment of new woody plants. High levels of browse on woody riparian plants is also an overall indicator of high grazing intensity, which can lead to invasion by invasive and disturbance-caused plants that do not perform riparian functions as well as native plants. The amount of riparian area covered in deep binding roots is another important measurement of riparian health because roots dissipate the erosive energy of high flows during floods and trap sediment to build up and restore stream banks. Finally, the amount of human-caused bare ground in the riparian area is important to measure for the same reasons described above for rangelands.


Eating woody vegetation


Cottonwood Seedlings

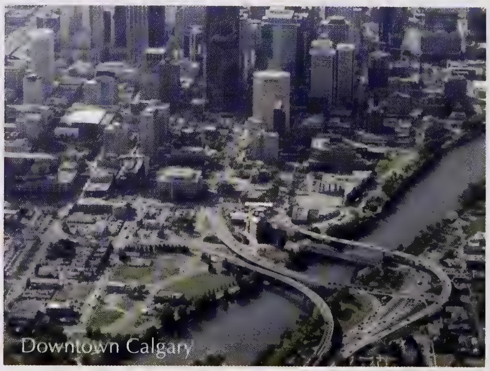

Cattle grazing in riparian area

The land use indicators proposed in this report are pressure indicators that measure human activities occurring on the land base of a watershed. Indicators of land uses are linked to environmental outcomes because they impact water quantity and quality requirements for human needs as well



Calgary smog

Bare ground at a clear span bridge crossing.



Downtown Calgary

Erosion of riparian bike path

Spyhill Landfill

Deerfoot & Memorial Interchange, Calgary

as the maintenance and restoration of aquatic and riparian ecosystem health. The land use indicators proposed here (Table 2) measure:

- a variety of types of human-altered land and constructed landscape features
- human population and dwelling unit density
- amounts of agricultural and non-agricultural fertilizers and pesticides applied to the land

Besides monitoring the human footprint, population, and dwelling unit density across entire watersheds, these should also be reported separately for the area of watersheds within a set distance (e.g., 500 m) of waterbodies and areas where wetlands exist or existed in the past. The indicators could be expressed in terms of the percentage of this total area covered by certain land use types or the density of certain land use features over a given shoreline distance. This would reflect the greater impact that land use activities can have in these areas as opposed to elsewhere within watersheds.

To define thresholds and targets for land condition and pressure indicators, watershed scale estimates of soil erosion rates (a land condition indicator, see Table 1) and runoff volumes and rates (a water quantity pressure indicator, see Table 4) should be obtained by modelling current land use scenarios and then an array of new scenarios capturing potential land use changes that could occur (e.g., Fohrer et al. 2005). Changes to the estimated soil erosion rates and runoff volumes and rates should then be compared to water quantity and quality requirements for various designated water uses in the watershed (Table 2). This would require the use of a watershed scale water quality model (e.g., Soil and Water Assessment Tool (SWAT); see Gassman et al. 2002, Grunwald and Qi 2006). Appropriate land use types and thresholds for land use intensity for different areas of watersheds should then be based on modelled changes to land use that will still allow the requirements for the various designated water uses to be met. If some water use requirements are not being met under the current land use scenario, the same approach could be used to determine what land use changes (i.e., land use targets) might allow the designated water uses to be met. As more studies are conducted relating land use intensity to aquatic and riparian ecosystem health (e.g., Wang et al. 1997, Moffatt at al. 2004), land use thresholds and targets defined based on soil erosion and runoff should be compared with the results of these studies to determine whether these erosion and runoff-based outcomes will also protect this important area of the environment.

LAND USE CAN TAKE MANY DECADES TO CHANGE AND LAND QUALITY MAY NOT RESPOND TO THESE CHANGES AS QUICKLY AS OTHER COMPONENTS OF THE ENVIRONMENT SUCH AS WATER QUANTITY AND QUALITY. THEREFORE, SHORT, MEDIUM, AND LONG-TERM LAND TARGETS MAY NEED TO BE DEFINED.


Cattle grazing near Waterton

Table 2. Land pressure indicators measuring human activities on the land base of watersheds.

Land pressure indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Total human footprint classified by: 1. Land cover types, for example: • irrigated crop • non-irrigated crop • irrigated cultivated pasture • non-irrigated cultivated pasture • forest clear-cuts • pits or mines • industrial development • urban residential • rural residential • impervious surface 2. Landscape features, for example: • confined feeding operations & large dairies • oil & gas batteries • compressors or refineries • industrial processing plants • oil & gas wells • groundwater wells 3. Linear disturbance & stream crossing types, for example: • roads • rail lines • transmission lines • pipelines • seismic lines • dams	The level of land use in a watershed is directly related to the severity of environmental impacts on water supply & quality as well as aquatic & riparian ecosystem health. By identifying the areal amount & delineation of land use types & density of developed site types & linear disturbances, amounts of different types of pressures on these environmental components can be determined.	Changes to human footprint are a direct response to how land is used & managed.	Thresholds not determined yet, but could be set with respect to levels of land use resulting in unsustainable increases in runoff volume, erosion, & pollutant loadings as well as degradation of aquatic ecosystem health. Targets could be set based on expert opinion & stakeholder consultation (e.g., target to reduce impervious areas in Calgary to ≤30% by 2036, see City of Calgary 2006a).	Better understand the effects of land use on other environmental components (e.g., water quantity, water quality, aquatic & riparian ecosystem health). Direct & encourage changes to how land is managed & developed based on correlations found between land use and environmental condition.	Measured over entire watersheds by combining existing land use/land cover data from multiple spatial databases.	Should be monitored on an ongoing basis as new development occurs & spatial databases are updated. Status of all cover types, landscape features, linear disturbances, and stream crossing types should be recorded to ensure only active and relevant human disturbances are recorded.	Human footprint is already being monitored by federal, provincial, and municipal government agencies as well as academic researchers & non-government organisations. Additional costs would involve extracting & compiling relevant data from multiple sources for an overall estimate of total human footprint within watersheds.
Human population • population density • dwelling unit density	An indicator of residential land use intensity.	Depends on municipal development plans.	Few thresholds have been determined yet, but the Town of Okotoks provides an example: a limit has been set for its maximum population size based on the capacity of the Sheep River to supply municipal drinking water (Town of Okotoks 1998).	Direct municipal planning in terms of setting targets & limits for human & dwelling unit density. Targets & limits may vary for different regions within a municipality & be set for the short, medium, & long-term.	Measured over entire watershed by breaking federal &/or municipal census subdivisions apart into separate watersheds. Areas of concern would be cities, suburban areas, towns, & rural residential areas.	Should be monitored on an ongoing basis as new census data becomes available. National censuses are conducted every 5 years. Municipal censuses may be more frequent.	Census data is already being collected. Additional costs involve compiling data from multiple sources & subdividing data according to watershed boundaries.


Quading in Crowsnest Pass


Confined feeding operations


Prairie oil refinery

Table 2 continued. Land pressure indicators measuring human activities on the land base of watersheds.

Land pressure indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Agricultural manure & fertilizer application rates	These indicators reflect the amount of nutrients and pathogens applied to the land, which can in turn enter the aquatic environment through surface runoff & affect water quality required for human use & protection of aquatic life.	Depends on agricultural practices & regulations.	Thresholds not determined yet, but could be set using models that predict erosion & runoff rates & volumes. Limits on manure & fertilizer application rates could be based on a watershed scale water quality model & water quality requirements for human use & protection of aquatic life.	Allow correlations between manure & fertilizer application rates & water quality to be more thoroughly evaluated. Results could be used to prompt & direct changes to agricultural practices.	Should be measured over entire watersheds.	Should be monitored regularly. Agricultural Censuses are conducted every 5 years, but if separate surveys in individual watersheds were used to collect these data, they could be conducted more frequently (e.g., annually).	Census data is already being collected, but only provides the area of manure and fertilizer application and the type of application. Actual quantities applied, when application occurred, and the specific location of application would need to be collected separately, possibly by individual WPACs & WSGs in partnership with Alberta Agriculture and Food.
Agricultural & non-agricultural pesticide use	Indicators reflect amount of pesticides applied to land, which can in turn enter the aquatic environment through surface runoff & threaten water quality required for human consumption, protection of aquatic life, irrigation, & recreation.	Depends on levels of use & whether use is regulated.	Thresholds not determined yet. Targets or municipal bylaws banning certain types of use may be more appropriate.	Identify areas & sectors with high levels of pesticide use. Target beneficial management practices & possibly re-examine regulation of use for these sectors.	Rough estimates of total pesticide sales within watersheds can be determined (City of Calgary 2006b, AENV 2000).	Sales should be recorded annually. Current province-wide monitoring is occurring every 5 years, with monitoring in Calgary and Edmonton occurring annually.	Data on pesticide sales is already being collected by Alberta Environment. Additional costs would involve increased sampling frequency and extracting, compiling, and analyzing data for an estimate of sales within watershed boundaries.

2.2 Water Quantity

As human activities expand, research is showing that ***the health of entire river ecosystems depends on the natural flow regime, including the water quality, fish and benthic invertebrates, riparian vegetation, and physical river channel.*** In terms of water quality, high and low flows can have both positive and negative effects. In southern Alberta, high temperature, low dissolved oxygen, and point and non-point sources of nutrients and sediments are the primary water quality concerns for the protection of aquatic life (Koning et al. 2006, Cross et al. 1986). Since rivers in southern Alberta originate from snow melt in the mountains, higher flows will buffer against human-caused water temperature increases. Higher flows will also increase the amount of dissolved oxygen in rivers by increasing the surface area over which oxygen can dissolve into the water and by lowering water temperature and increasing the solubility of oxygen.

ALL STREAM AND RIVER SYSTEMS DRAINING WATERSHEDS HAVE NATURAL FLOW REGIMES WITH HIGH FLOWS DURING RUNOFF EVENTS AS WELL AS LOW FLOWS DURING DRIER PERIODS IN THE SUMMER AND WINTER. FLOWS ALSO DIFFER FROM YEAR TO YEAR BECAUSE SOME YEARS WILL HAVE MORE PRECIPITATION THAN OTHERS.

Water quantity can also affect nutrient concentrations in a number of ways. Higher flows can scour away sediments rich in organic matter and nutrients, as well as the associated algae and macrophytes, which in turn will alleviate the cause of low levels of dissolved oxygen (Sosiak 2002). However, if high flows are due to runoff from agricultural or urban areas, then they may reduce water quality by increasing sediment and nutrient concentrations and lowering dissolved oxygen levels. With lower concentrations of all types of water quality contaminants entering waterbodies, less water is needed to dilute these loadings and sustain adequate water quality. However, more water than would naturally be flowing in rivers is needed downstream of some cities in southern Alberta during winter low flow periods to dilute ammonia (see section 2.3) from wastewater treatment plants, which can be toxic to aquatic life (Clipperton et al. 2003). Occasionally, higher than natural flows may also be necessary in winter (due to ice cover) and in the summer (due to high water temperatures) to ensure dissolved oxygen levels are high enough to support coldwater fish species.

Oldman River Flooding

Castle River

Fish and benthic invertebrates are another component of river systems that are dependent on the natural flow regime. The natural flow regime represents a condition that fish and benthic invertebrate communities have become adapted to, and their abundance and distribution will match the availability of physical habitats, the range of water quality, and the supply of food from upstream sources that high and low-flow periods provide (Clipperton et al. 2003). Water depth and velocity are dependent on


Low late summer flows


Low flows below Oldman River Dam

flow and each species and life-stage has its own optimum for these habitat conditions. As river flows increase or decrease, the amount of suitable habitat available for some species and life-stages will increase, while for others it may decrease. Unseasonably low flows resulting from dams and diversions can greatly reduce the amount of physical habitat space in rivers, thereby limiting the diversity, distribution, and abundance of species. Spawning sites as well as deeper habitats used as refugia during high summer temperatures and low winter flows may become too shallow or inaccessible from the main river channel. Low flows can also disrupt upwelling of alluvial groundwater, which can be critical to supporting these habitats. Another impact of low flows is that they may not be sufficient to flush silt and sand downstream so it does not buildup in the spaces between the larger gravel, cobble, or boulders (Clipperton et al. 2003). These spaces incubate the eggs of many aquatic species and also provide cover habitat for juvenile and adult life stages. Higher flows are also important for fish and benthic invertebrates because they mobilize the material making up river channels and create habitat features such as riffles, pools, runs, and point bars (Clipperton et al. 2003). High river flows are also important because they ensure food from upstream sources both within the river and the surrounding land is carried downstream to support fish and benthic invertebrates. Variation in river flows can also affect water quality parameters, which control the distribution and abundance of fish and benthic invertebrates. Downstream of dams there is generally a more stable flow regime than naturally existed. Reduced turbidity resulting from sedimentation in the upstream reservoir can increase algal growth and change the abundance and diversity of benthic invertebrates downstream of the dam (Clipperton et al. 2003). Cooler water temperatures downstream of bottom-release reservoirs, or warmer water temperatures downstream of top-release reservoirs can shift the distribution of cold and cool-water fish and benthic invertebrate species.

The natural flow regime can be altered in three ways that will lead to impacts on riparian vegetation (Mahoney and Rood 1998). First, dams can attenuate spring flood events not allowing for river banks to be scoured so there is bare ground suitable for seedling establishment. These flood events are also important for inundating and saturating the floodplain with water so existing riparian plants far from the riverbank are provided with moisture. A second way


1995 flood, Oldman near West Lethbridge

the natural flow regime can be altered that will impact riparian vegetation is, if flows are reduced too quickly, developing riparian seedlings and saplings will not have enough time to grow deep roots that can draw water up from the riparian water table and the plants will dry out and die. Finally, if summer flows, which are already naturally low, are reduced even further by offstream diversions and sufficient flows are not maintained, riparian plants will become drought stressed and over a number of years this can progressively lead to loss of leaves, plant die back, and eventually complete mortality. In southern Alberta the best known example of the effects of an altered flow regime on riparian vegetation is the widespread loss of cottonwood trees downstream of dams and diversion structures (Mahoney and Rood 1998, Rood and Mahoney 2000). Changes to the magnitude of peak flows, the rate at which flows recede following spring flood events, and reduced flows during summer months have all played a role in this process. As the impacts of flow management have become better understood, managers have responded by making changes to dam operations to promote cottonwood restoration. In particular, on the St. Mary River below the reservoir more natural flow declines following flood peaks have been implemented and a three-fold increase in the minimum permissible flow has also occurred. This led to a seedling recruitment event in 1995, although the long-term growth and reproductive success of these individuals still appears to be limited by the minimum flow released from the dam.


Cottonwood saplings

Still another component of rivers that shows how these ecosystems are dependent on the natural flow regime is the physical river channel (Clipperton et al. 2003). Besides minimum flushing flows required to prevent fine sediment from building up, higher flows are necessary to mobilize bed material, form new river channels, and keep existing channels from becoming too narrow, overgrown with vegetation, and prone to flooding. These higher flows also bring woody debris into river channels from the adjacent floodplain, which traps sediment and can provide a starting point for the formation of new channel features.


Prairie river channel features

So, clearly the entire river ecosystem is adapted to and dependent on seasonal and year-to-year variation in the natural flow regime, and although scientists are still developing methods to directly measure the response of river ecosystems to flow alteration, it is now widely accepted that the greater the alteration to the natural flow regime, the greater the effect will be on river ecosystems.

2.2.1 Water quantity condition and pressure indicators

To address the fact that the natural flow regimes of rivers and streams throughout southern Alberta have been altered to varying degrees, the WPACs and WSGs should select and monitor some water quantity condition and pressure indicators that are linked to the broader environmental outcomes they are trying to obtain. Monitoring these indicators should provide direction for efforts to maintain or restore flow regimes that will ensure adequate water quantity and quality for all designated uses and protection of aquatic and riparian ecosystem health.


Oldman Dam

Currently, the natural flow regimes of the mainstem rivers in southern Alberta have been altered primarily by dams and diversions. The South Saskatchewan River Basin Water Management Plan has set a new direction for future water management in the Bow, Oldman, and South Saskatchewan sub-basins (Figure 2) by placing a moratorium on new water licences (AENV 2006a). These river basins are under pressure and impacts of dams and diversions on the aquatic environment of all reaches are now recognized with some reaches being heavily impacted or degraded (AENV 2006a). In the Milk River basin a moratorium has already been in place since 1987 for all types of water licences except municipal drinking water licenses (AENV 2004), and the South Saskatchewan River Basin Water Management Plan recognizes the limit for water allocations will be reached in the Red Deer basin within three to four decades (AENV 2006a). Given the level of allocation on all mainstem rivers in southern Alberta, restoring the natural flow regime is clearly not realistic. However, water quantity condition and pressure indicators selected by the WPACs and WSGs for these rivers should still provide direction and impetus to work towards more natural flow regimes that will maintain and restore water quality and aquatic and riparian ecosystem health.

Flow regimes for regulated streams and rivers in southern Alberta could be evaluated by simply monitoring the overall deviation of recorded flows from naturalized flows and various flow regime benchmarks set by environmental managers and scientists (Table 3). These deviations could be used as condition indicators because naturalized flows and some of the flow regime benchmarks are inherently linked to outcomes to protect water quantity and quality and aquatic and riparian ecosystem health. Deviations could be expressed in terms of flow (cubic meters per second) or volume (cubic decametres) deficits.

On unregulated streams and rivers the natural flow regime will be impacted by changes to land cover rather than by water management activities. If human land use activities that alter or remove natural vegetation are occurring within the watersheds, changes to surface runoff are possible, and water quantity pressure indicators that could be monitored are changes to annual runoff rates and volumes modelled at the watershed scale as well as changes to the observed magnitude and frequency of base and peak flow events (Table 4). The effects of changes to land cover on flow regimes have not been measured for most of southern Alberta, and as forestry, oil and gas extraction, agriculture, and urbanization intensify (Timoney and Lee 2001) and water becomes a scarcer resource (Byrne et al. 2006), it will be increasingly important to have accurate models predicting runoff rates and volumes under changing land uses and accurate sector-specific measurements of water use to determine whether water quantity outcomes are


Mountain Pine Beetle effects on landscape


Erosion and runoff from a forestry road


Calgary street flooding


Byron Creek flowing through area burnt by the Lost Creek Fire in the Crowsnest Pass area, 2003

being met. Thresholds for these indicators could be defined in terms of what changes to runoff and base and peak flows will still support the broader outcomes related to water quantity and quality and aquatic and riparian ecosystem health. Runoff from all areas where natural land cover has been altered should be considered, including harvested forests, roads and other impervious surfaces, cultivated land, and construction sites. Urbanization in particular can lead to large changes in flow regimes through increased runoff and decreased groundwater recharge resulting from impervious surfaces. In areas already urbanized, a target could be to reduce the rate and volume of runoff from land that has already been developed to a more natural level by removing unnecessary impervious surfaces.


Nose Creek Construction


Irrigation pump unit


Alley runoff

Beyond changes to runoff and base and peak flows, the actual amount of water being removed from and returned to streams and rivers as a result of human activities could also be monitored as a pressure indicator. The indicators could be measurements of all water diversions licensed by Alberta Environment and any associated return flows. Although the volume of water allocated for use in southern Alberta is known, this does not translate into the actual volume of water diverted from and returned to

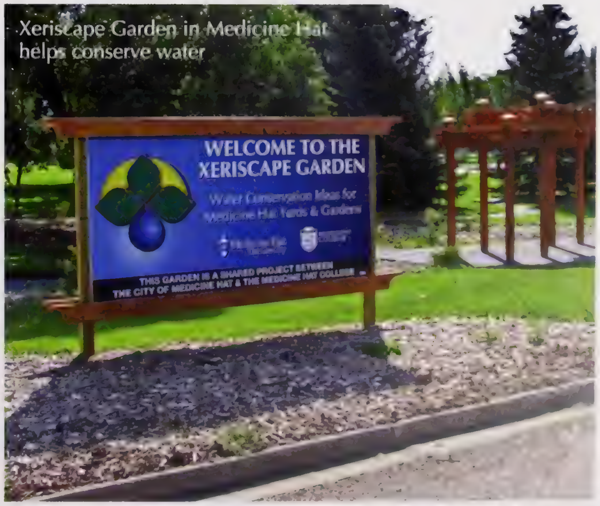

Irrigation

Irrigation pipeline installation in the St. Mary Irrigation District helps conserve water

streams. Alberta's *Water for Life* strategy has set a target of increasing efficiency and productivity of water use in Alberta by 30% by 2015 from 2005 levels, and water conservation is one of the three key directions on which actions outlined in the strategy are based (AENV 2003).

- Water conservation is any beneficial reduction in water use, loss, or waste, and can be achieved through water management practices that improve the use of water resources to benefit people or the environment (AENV 2007).
- Water efficiency is the accomplishment of a function, task, process, or result with the minimal amount of water feasible (AENV 2007).
- Water productivity is the amount of water that is required to produce a unit of any good, service, or societal value (AENV 2007).

CLEARLY, TO ACHIEVE TARGETS FOR WATER CONSERVATION, EFFICIENCY, AND PRODUCTIVITY, IMPROVED MONITORING AND REPORTING OF DIVERSIONS AND RETURN FLOWS WILL BE CRITICAL SO THAT SECTOR-SPECIFIC TARGETS CAN BE SET AND EVALUATED ON A PER CAPITA OR PER UNIT BASIS.



Xeriscape Garden in Medicine Hat helps conserve water

Table 3. Water quantity condition indicators measuring deviation of recorded flows from naturalized flow, Instream Flow Needs, Water Conservation Objectives, and Instream Objectives.

Water quantity condition indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Deviation of recorded flows from naturalized flows	Better protect aquatic & riparian ecosystems during periods of high & low flows by identifying reaches under greatest stress.	Flows falling outside the range of naturalized flow variability are partly the result of dams, diversions, and changes to land cover.	Actions can be targeted to reduce water use & impacts of dams, diversions, & land use for reaches under stress.	Efforts to bring the recorded flow regime closer to the natural regime can be targeted to reaches with the greatest deviations.	This indicator reflects all upstream water diversions and land use impacts; flow deviations should be reported at all gauging stations where naturalized flows are calculated.	Annual summaries of deviations reported on a seasonal, monthly, or weekly basis would be valuable to the WPACS and WSGs.	Costs associated with calculating naturalized flows at more gauging stations and on a continual basis, rather than irregularly every 5 to 10 years.
Deviation of recorded flows from Water Conservation Objectives (WCOs)	Determine where & when SSRB WCOs are and are not being achieved.	Whether WCOs are met depends on water use downstream of dams & diversions & how these structures are operated.	WCOs are water management targets set by AENV for the SSRB. They are 10% of the existing instream objective or 45% of the natural flow (whichever is greater).	Focus efforts to increase water conservation, efficiency, and productivity to achieve these objectives in areas & during times when objectives are not met.	Deviations from WCOs should be reported at all gauging stations.	Deviation of recorded flows from WCOs should be reported annually on a seasonal, monthly, or weekly basis.	Because WCOs rely on naturalized flow data, costs would be associated with calculating naturalized flows, as above.
Deviation of recorded flows from Instream Flow Need (IFN) values determined for water quality, fish, & riparian health.	Determine where & when IFNs are achievable. Focus conservation & BMP efforts on these times & locations to decrease deviation from IFNs.	IFNs are generally achievable under natural flow (water quality IFNs sometimes an exception). Deviation from IFNs depends on water use & how dams & diversions are operated.	IFNs are objective estimates of minimum flows required to maintain ecosystem components, but they do not represent true thresholds beyond which ecosystem effects occur.	Focus efforts to increase water conservation, efficiency, and productivity to achieve these objectives in areas & during times when IFNs are not met.	Deviations from IFNs should be reported for reaches of all streams where IFN values exist.	Annual summaries of deviations reported on a seasonal, monthly, or weekly basis would be valuable to the WPACS and WSGs.	Because IFNs rely on naturalized flow data, costs would be associated with calculating naturalized flows, as above.
Deviation of recorded flows from Instream Objectives	Ensure these minimum regulated flows are being achieved.	Whether Instream Objectives are met depends on water use and whether dams and diversions are operated to ensure minimum flows are maintained.	Instream Objectives are regulations, which dams and diversions must operate by. They define minimum regulated flows, or thresholds, which flows downstream of dams and licensed water diversions must stay above.	In streams or reaches where these minimum regulated flows are sometimes not being met, management of dams and diversions should be improved and water use restrictions better enforced.	Deviations from Instream Objectives should be reported at all gauging stations.	Deviations from Instream Objectives should be reported at all gauging stations where Instream Objectives exist.	Deviation of recorded flows from Instream Objectives should be reported in real-time so infringements and violations can be identified instantaneously.

Table 4. Water quantity pressure indicators measuring the amount of water being removed from and returned to streams and rivers as a result of human activities.

Water quantity condition indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Water used by • irrigation districts • private irrigators • industry • cities, towns, & municipalities	Water use provides basic information for monitoring volume, rate, & timing of water removed & returned to rivers. Reach-specific water balancing can be used to compare relative contribution of various users to overall use & flow deviations from naturalized flow, WCOs, and IFNs.	Changes in water use are a direct response to how water is used by agricultural, residential, commercial, industrial, & institutional users.	Licensed volume, rate, & timing restrictions exist & are being met by large users, but there is uncertainty around small users. All users could set targets to reduce water use (e.g. overall use should be reduced if no growth, if growth in irrigation or population then use should be reduced on a per unit basis.)	Provides basic information needed to work towards reducing use on a total or per unit basis. Can target biggest users in individual reaches when implementing water conservation plans. Headworks can be operated to match supply & demand. Ensure fair use during droughts. Provide information needed to transfer allocated water in the SSRB.	All diversions within watersheds should be monitored. Monitoring of large diversions is already occurring, but return flows need improved monitoring. Smaller users need direction on improved & consistent monitoring techniques.	Continuous monitoring should be required for all water users. Real-time reporting required for all major users. Less frequent reporting for smaller users.	Higher maintenance & possibly operational costs associated with continuos, real-time monitoring.
Change in magnitude & frequency of base & peak flow events as well as annual runoff rates & volumes modelled at the watershed scale in watersheds where natural land cover is or will be altered.	The observed or model predicted estimates of the magnitude & frequency of base & peak flow events can be compared to predevelopment records or estimates to determine whether existing or proposed land use has or will alter runoff patterns so they are outside the natural range of variability. Predevelopment estimates could be based on a natural land cover scenario.	In addition to the effect of human alteration of natural land cover, runoff rates & volumes & the magnitude & frequency of base & peak flow events are affected by trends in precipitation & temperature that are occurring as a result of climatic change.	Some urbanized areas in southern Alberta have maintained the pre-development magnitude & frequency of base & peak flow events & runoff rates & volumes by using runoff from impervious surfaces for irrigation (e.g., Hamptons subdivision, see WER 2005). Setting pre-development conditions as targets at the watershed scale may be feasible, but has not been done.	Knowledge of how changing land use will impact surface water supply will be critical in evaluating land development plans that will alter natural cover.	The magnitude & frequency of base & peak flow events is being recorded at all gauging stations. New stations may need to be added in watersheds undergoing extensive changes to natural land cover. Runoff rates & volumes must be modelled over enter watersheds.	The magnitude & frequency of base & peak flow events is recorded over many years using continuous records of flow. Runoff rates & volumes can be modelled on an annual basis.	New costs would be associated primarily with collecting land cover data & modelling runoff rates & volumes at the watershed scale.


Rain barrels help conserve water

Water being released from the St. Mary Dam

Pressure indicators measuring runoff and base and peak flows as well as pressure indicators measuring water use should be used by the WPACs and WSGs to identify which human activities are having the greatest impact on condition indicators evaluating the recorded flow regimes of streams and rivers in their watersheds (Table 4). Activities with the greatest negative impact can then be addressed.

In terms of assessing the state of the recorded flow regime relative to flows that are deemed to be socially, economically, and scientifically acceptable, flow regime benchmarks will be used. Various benchmarks have been set to define appropriate flows for streams and rivers in southern Alberta (Table 3). Generally the benchmarks vary as a function of natural flow, but in some cases they are based on a single minimum flow value. Benchmarks that preserve some of the natural flow variability provide better protection for river ecosystems than those that allow the variability in flows to be removed as flows are kept at a constant minimum value (Poff et al. 1997). Three types of benchmarks relevant to managing flows in southern Alberta are Instream Flow Needs (IFNs), Water Conservation Objectives (WCOs), and Instream Objectives. IFNs are scientifically determined flow requirements based on a percentage of the natural flow that is thought to be necessary to sustain the health of various components of river ecosystems (Clipperton et al. 2003). For example, IFNs have been derived for the mainstem rivers of the South Saskatchewan River Basin downstream of the major water management headworks to protect water quality, fish habitat, riparian cottonwoods, and channel maintenance (Clipperton et al. 2003). IFNs are not legislated flows and cannot be enforced under Alberta's *Water Act*. WCOs, on the other hand, are flow benchmarks based on public input and the government's decision in terms of what is deemed a reasonable and socially acceptable trade-off between environmental protection and socio-economic needs for water (AENV 2006a). Instream Objectives are used as operational numbers setting restrictions on existing water licences based on Alberta's *Water Act*. These objectives define minimum regulated flows that must remain in rivers downstream of dams and licensed water diversions. In the South Saskatchewan River Basin Water Management Plan, WCOs for the Bow, Oldman and South Saskatchewan River sub-basins above and below major dams and diversions were set as the greater of 45% of natural flow or the existing Instream Objectives plus 10%. On the Red Deer River upstream of the Blindman River the WCO was set as the greater of 45% of natural flow or 16 m^3/sec, while downstream of the Blindman River the WCO was set as the greater of 45% of natural flow or 10 m^3/sec. Although Instream Objectives are the only benchmarks currently used as operational controls on how much natural flows can be reduced on rivers in southern Alberta, it would be useful to know where recorded flows lie with respect to all three benchmarks (IFNs, WCOs, and Instream Objectives) so it is clear when and where these objectives are and are not being met. Comparing recorded flows to naturalized flows would also indicate the absolute amount by which flows have been altered.

2.3 Water Quality

Water quality is one of the first things measured when assessing state of the environment because it reflects all activities occurring in a watershed and can respond to changes in these activities more quickly than aquatic biological indicators. However, water cannot simply be of 'good' or 'bad' quality, because it depends on what the water will be used for.

WHETHER HUMANS USE WATER FOR AGRICULTURE SUCH AS IRRIGATION AND STOCK WATERING, RECREATION SUCH AS SWIMMING AND BOATING, SUPPORTING COMPONENTS OF AQUATIC ECOSYSTEMS SUCH AS SPORT FISH, COMMERCIAL AND INDUSTRIAL PROCESSING, OR AS A SOURCE OF DRINKING WATER. THESE USES ALL HAVE DIFFERENT REQUIREMENTS FOR WATER QUALITY. WATER THAT IS SUITABLE FOR ONE USE MAY NOT BE SUITABLE FOR ANOTHER.

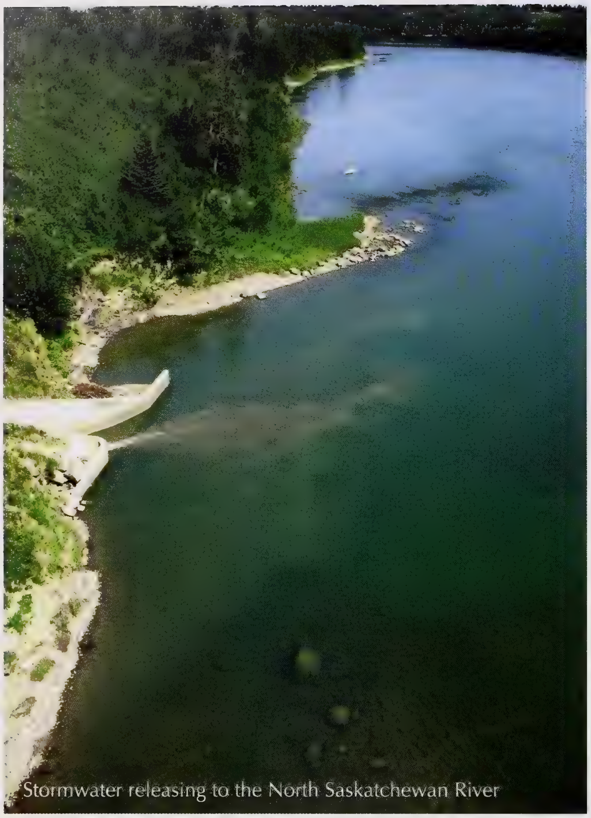
Angler with a Trout

Off-stream watering

Children swimming in a prairie reservoir

Glass of drinking water

McCain's French fry plant in Coaldale



Water quality can be degraded by point and non-point sources of contamination (see diagram on pg. 34). While non-point sources include atmospheric deposition, surface runoff, and contaminated sediments and groundwater, point sources are effluent released from single sources such as municipal wastewater treatment plants and industrial facilities. Most of the improvements in water quality that have been achieved to date are the result of the reduction of point source pollution because these sources are easy to identify and regulate (Poole at al. 2004). Individual point sources have been managed effectively by improving treatment of the effluent, reducing effluent volumes, or eliminating the discharge altogether, but management issues still arise when there are many point sources providing effluent loadings. Today in many watersheds in southern Alberta loadings of suspended sediments and nutrients are greater from non-point sources than from point sources (Byrne et al. 2006, Koning et al. 2006). Unlike point sources, non-point sources are diffuse so it can be difficult to identify which of the sources is causing the most water quality degradation and to know how these sources can be controlled. To manage water quality effectively, a holistic perspective is needed that considers the whole system of inputs, processes, outputs, and feedbacks controlling this aspect of the environment.

Natural water quality parameters that are essential for aquatic ecosystems can still result in poor water quality if they become out of balance (Poole at al. 2007). Natural parameters that often lead to poor water quality include:

- total suspended solids
- nutrients
- dissolved oxygen
- temperature

These parameters are all proposed as water quality condition indicators (see Table 5).

Sediments can reduce the biological productivity of aquatic ecosystems by blocking sunlight from penetrating the water resulting in decreased plant growth (primary productivity), which may reduce the growth of organisms that feed on the plant material (secondary productivity) and are, in turn, the food source for fish and benthic invertebrates (DFO 2000). Sediments can harm fish and benthic invertebrates by:

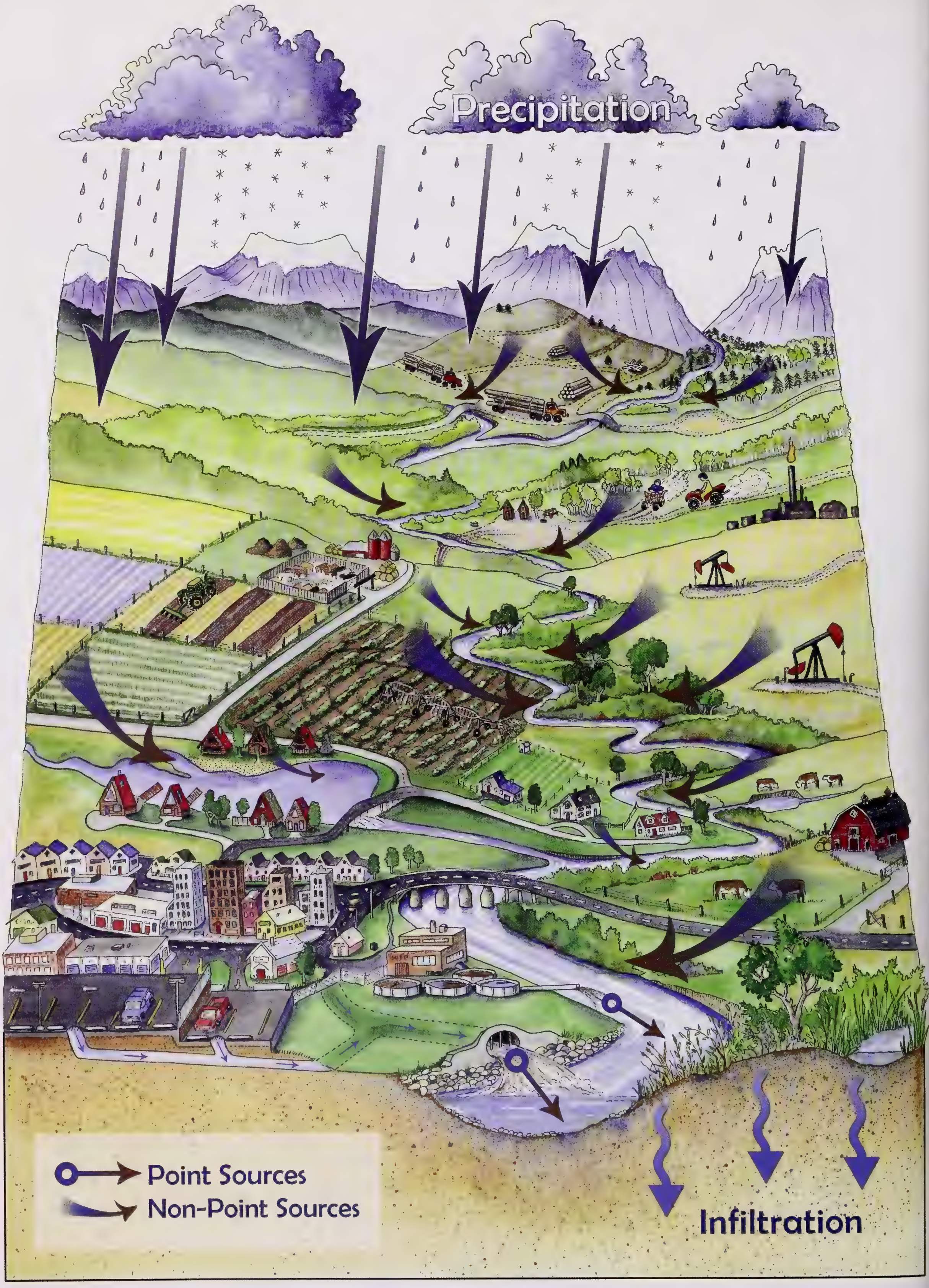
- leading to direct mortality
- preventing successful development of eggs and larvae in interstitial spaces of gravel spawning beds
- forcing movement to poorer habitats because existing habitat has been degraded
- increasing risk of predation and susceptibility to disease
- reducing abundance and catchability of food

Suspended sediments resulting from soil erosion in areas of bare ground is the primary water quality concern for agricultural, forestry, and urban runoff (Waters 1995). In urban areas sand deposited on roadways during the winter is also a significant source of sediment.

Sediment is an important contaminant because it is involved in transporting the majority of the phosphorus that enters surface waterbodies (Kronvang 1992). Particulate phosphorus that enters waterbodies attached to sediment

Table 5. Water quality condition indicators.

Water qualtity condition indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Water temperature & dissolved oxygen	A major concern for the protection of cold & cool water aquatic life. High & low temperatures can be an issue. Dissolved oxygen integrates cumulative effects of all point & non-point source nutrient loadings.	Water temperatures & dissolved oxygen levels cannot be entirely attributed to human activities. Also affected by natural factors.	Thresholds are well defined for some cold & cool water sport fish species (Taylor and Barton 1992), but less so for others (e.g., whitefish). Reach-specific objectives are required.	Temperature can influence dam & diversion operations (e.g. Highwood River-Little Bow diversion). Both indicators can identify reaches where variables are approaching critical thresholds. Effects of water management operations, land use, & point & non-point sources can be evaluated. Water quality models can be evaluated & updated.	Temperature & dissolved oxygen can change abruptly with distance downstream & over a river's cross-section, with isolated pockets of high & low values. Monitoring locations need to be carefully selected.	Continuous sampling is required because of diurnal & seasonal variation. Real-time reporting in critical areas is required to direct management actions to avoid problems such as fish kills before they occur.	Additional costs would exist for monitoring temperature & dissolved oxygen continuously at more sites than it is currently being done. However, at most gauging stations equipment for real-time reporting of data (i.e., river flows) already exists.
Nutrients: • Nitrogen • Phosphorus	A major concern for overgrowth of aquatic plants, low dissolved oxygen levels, & protection of aquatic life.	Nutrient levels cannot be entirely attributed to human activities. Also affected by natural factors.	Guidelines exist for some nutrients (CCME 1999: NO^{3+}, NO^{2-}; AENV 1999: total N & P), but reach-specific objectives required.	Identify critical reaches & sources of nutrient loadings, direct where to allocate resources to improve point & non-point source nutrient management.	Can change abruptly with inputs from tributaries & point sources (e.g., wastewater treatment plants).	Nutrient levels can change rapidly. Continuous sampling is necessary near point sources or if trying to capture extreme values. Sampling for background monitoring can be less frequent.	Additional costs exist for monitoring more frequently & at more sites than just the mainstem.
Total Suspended Solids	A major concern in terms of associated overall pollutant loadings, disturbance of the land base, & protection of aquatic life.	Cannot be entirely attributed to human activities. Also affected by natural factors.	Provincial (AENV 1999), federal (CCME 1999), & US (US EPA 2002) guidelines exist, but depend on knowledge of background (natural) levels of suspended sediment. Reach-specific objectives required.	Identify critical reaches & sources of sediment loadings in headwaters & downstream of urban areas. (e.g., stream crossings, riparian disturbance, construction, stormwater & wastewater).	Can change abruptly with inputs from stormwater, tributaries, & point sources (e.g., wastewater treatment plants).	Can change rapidly with snowmelt & storm events. Continuous monitoring is required to capture extreme values. Sampling for background monitoring can be less frequent.	Additional costs exist for monitoring more frequently & at more sites than just the mainstem.
Pathogens: • Faecal coliforms • *E. coli*	A major concern for drinking water, irrigation, & contact recreation.	Cannot be entirely attributed to human activities because of natural sources (i.e., wildlife).	Designated use guidelines exist based on *E. coli* for drinking water (Health Canada 2007) & based on faecal coliforms for recreation & irrigation (AENV 1999).	Counts above threshold identify reaches of concern, & further investigations should be done to identify sources of contamination.	Can change abruptly with changes in human activities.	Can change rapidly with snowmelt & storm events. Sampling frequency during these events should be increased.	Additional costs exist for monitoring more frequently & at more sites. Using turbidity as a surrogate measure may save money.

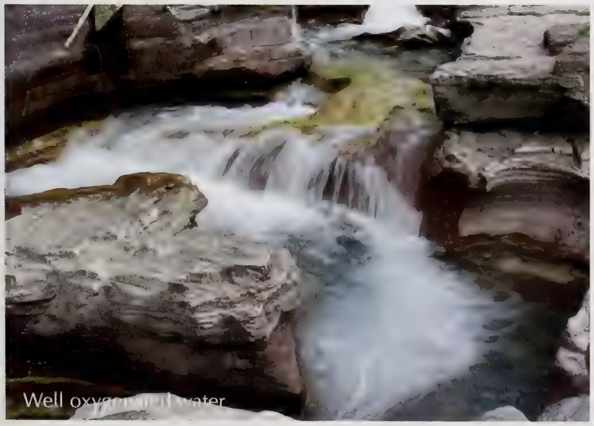

Precipitation
Point Sources
Non-Point Sources
Infiltration

can then be converted to its dissolved inorganic form making it available to aquatic plants (Waters 1995). A lesser amount of phosphorus can also be carried to surface waterbodies independent of sediment in its dissolved form, originating primarily from manure and fertilizers (Sharpley et al. 2001). Although less phosphorus is transported by runoff in the dissolved form, because it is directly available to plants it can have a significant impact on the aquatic ecosystem. Besides runoff, another significant source of dissolved phosphorus is municipal discharge from wastewater treatment facilities (Chambers et al. 1997).

Nutrients like phosphorus are essential for plant growth, but they can cause problems for aquatic life when they are the only factor limiting aquatic plant growth and the amount of nutrients entering a waterbody is too high, promoting excessive plant growth. Although plants produce oxygen during daylight hours through photosynthesis, at night the plant cells are only respiring and this uses up oxygen, reducing levels of dissolved

Dead fish floating in algae

Algae bloom



Well oxygenated water

oxygen, which is essential for aquatic life. Headwaters of rivers in the mountains and foothills of southern Alberta are particularly sensitive to nutrient inputs due to naturally low nutrient concentrations and the fact that they support coldwater aquatic life with high dissolved oxygen requirements. Low dissolved oxygen levels can result in large numbers of fish dying over a short period of time, and over the long-term can lead to the loss of desirable fish species such as trout.

Nitrogen is another nutrient that is essential for aquatic plant growth, but unlike phosphorus, most nitrogen enters surface water bodies in a dissolved form independent of sediment (Wetzel 1983). There are three important forms of nitrogen: nitrate, nitrite, ammonia. Nitrate is the most soluble form and does not bind to soil particles or form insoluble compounds with other elements in the soil. This means nitrates can easily enter surface waterbodies through runoff or percolate deep into the ground and contaminate groundwater. Transport of large amounts of nitrate to surface waters is a concern because it is rapidly taken up by aquatic plants and can lead to eutrophication in the same way phosphorus can. Furthermore, although nitrate is much less toxic than ammonia or nitrite, it still can be toxic to some forms of aquatic life. Ammonium is the ionic form of ammonia and unlike nitrate it does bind to soil particles and therefore is a more stable form of nitrogen in soil. However, concentrations of ammonium in the soil are generally quite low because it is quickly converted to nitrate. An exception is when a large volume of ammonium fertilizer or manure is applied to a field just before an intense precipitation event, which can wash concentrated ammonium into surface waterbodies. Some of this ammonium will then be converted to ammonia, which is toxic to fish and other aquatic life. Nitrite is the intermediate form of nitrogen between ammonium and nitrate and because the conversion process is rapid it does not accumulate in the soil. Like nitrate, nitrite does not bind to soil particles and is easily carried into surface water bodies by runoff.

Through the use of nitrogen fertilizers and manure application for crop production, the agricultural sector is a large contributor of non-point source nitrate to surface and ground waters. Limits have been put in place on the amount

Manure Spreading

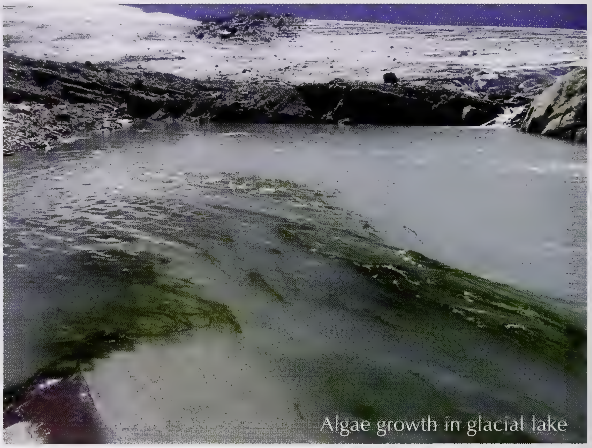
of nitrogen in manure that can be applied to crops to try to reduce the amount being carried by runoff into surface waters or leaching into groundwater supplies (Sharpley et al. 2001). However, when intensive livestock operations produce large amounts of manure and it is used as fertilizer, correct application for nitrogen requirements still results in excess phosphorus being applied to crops (Sharpley et al. 2001). This is because unlike commercial fertilizers where both nitrogen and phosphorus concentrations can

Anhydrous ammonia fertilizing

be matched to crop requirements, the ratio of nitrogen to phosphorus in manure is fixed. Therefore, manure applications can lead to a build up of phosphorus in the soil and increased phosphorus inputs to surface waters through runoff. As a result, efforts to apply phosphorus concentrations that more closely match crop requirements and to minimize soil erosion and runoff are very important for avoiding phosphorus contamination of waterbodies.

Atmospheric deposition of nitrogen and phosphorus through rain, snow, and gaseous and particulate (dust) transport can also be important non-point sources of nutrients in areas of intense agricultural activity (Wetzel 1983). Ammonia gas can be lost when manure or ammonia-based fertilizers are applied to fields under warm, dry conditions and are not mixed into the soil. Although most of the ammonia is re-deposited within a few hundred metres, it still may not be used by the intended crops and may runoff into surface water bodies. Burning biomass such as fossil fuels and forests, intensive livestock operations, and industrial activities can all cause nitrogen and phosphorus-bearing particles to become airborne and release nitrogen gasses into the atmosphere.

Water temperature is another critical natural parameter that can be affected by human activities. Research on the effects of temperature on fish, benthic invertebrates, and primary producers has shown that temperature is the single most important parameter determining the distribution and abundance of aquatic species (reviewed by Rivers-Moore and Jewitt 2006). Changes to water temperature can therefore pose a threat to aquatic ecosystem health. Beyond the background effects of solar radiation and meteorological conditions, dams and diversions are generally the most significant factor affecting water temperature in southern Alberta. Temperatures can be artificially decreased by discharges of deep, cold water from the bottom of thermally stratified reservoirs, while discharges from the surface of a reservoir through the



Algae growth in glacial lake

spillway can artificially increase water temperature. Offstream diversions can also increase water temperature by reducing the volume of water in rivers resulting in more pronounced effects of solar radiation. Besides dams and diversions, surface runoff from logged, agricultural, and urban land may be warmer than from land covered with natural vegetation, although the effects on water temperature in mainstem rivers are poorly understood.

Carseland Weir and Diversion

Besides the harmful effects of low dissolved oxygen associated with nutrient inputs, the overall increase in primary and secondary productivity that the nutrients cause can result in higher concentrations of suspended organic material in the water and reduced water clarity (measured as an increase in turbidity or total suspended solids). Beyond the immediate aesthetic concerns, this may cause water treatment problems if the water is used as a source for municipal drinking water or commercial processes. Taste and odour problems may arise and the chlorine used to disinfect the water can react with the suspended organic matter resulting in trihalomethanes being formed as a by-product (Davies and Mazumder 2003). These compounds are considered a human health risk at high concentrations, and governments have set limits on permissible levels in drinking water.


Recreational water use, floating down the Oldman River in Lethbridge

Another drinking water quality concern related to nutrients is that groundwater can be contaminated with high concentrations of nitrogen, which can have toxic effects on humans. This is a concern because groundwater is a significant source of water supply in Alberta, especially for human consumption in rural municipalities and individual households and for stock watering on farms (Komex 2005). Beyond concerns around human health, high nutrient levels in surface water can cause toxic phytoplankton or cyanobacteria blooms, and if livestock use this water, they may die. Excessive plant and algae growth can also cause problems for municipal, agricultural, recreational, and industrial water users by clogging waterways, irrigation canals, and intake pipes.

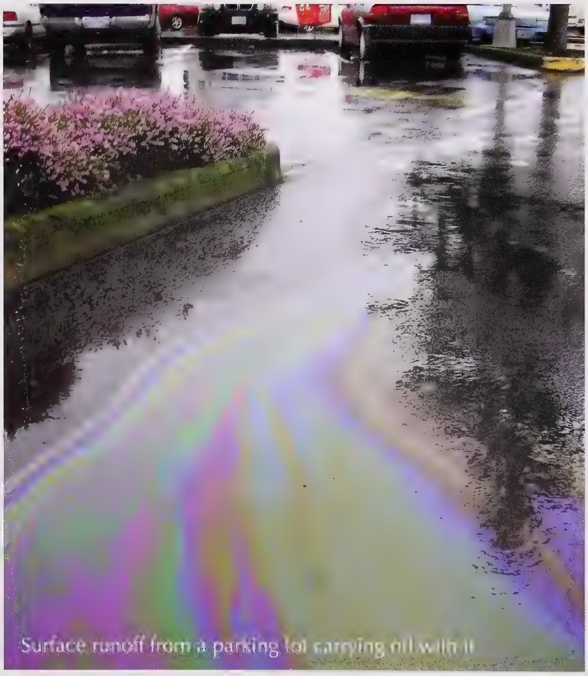
Beyond imbalances in total suspended solids, nutrients, dissolved oxygen, and temperature, pathogens can also pose a risk to human health when water is used for irrigation, recreation, and drinking. Gastrointestinal illness can be caused by eating unwashed produce, swallowing raw water, or drinking contaminated treated water. Significant sources of pathogens to waterbodies can include:

- sediment and nutrient inputs from runoff
- manure applied to crops or accumulating around areas where livestock are confined
- livestock accessing waterbodies to drink
- waste from domestic pets in city parks
- flocks of waterfowl
- wastewater treatment plants or lagoons

In general, microbial communities will be more abundant in eutrophic waters, since they are often also associated nutrient inputs (Mackie 2001). Agricultural runoff is a significant source of pathogens to surface water, and together with loadings from other non-human sources, can exceed loadings from wastewater treatment plants, especially when enhanced treatment has drastically reduced loadings from these facilities (Saffran 2005). However, direct release of untreated human sewage from leaking septic systems, overflowing lagoons during floods, and cross-connections between the stormwater and sanitary sewage systems can still lead to localised wastewater-related problems.

The two main groups of pathogens that are a concern for human health are protozoa and bacteria, and beyond monitoring total suspended solids as a general indicator for potential pathogen contamination, specific types of protozoa and bacteria may also be monitored by drinking water treatment plants to assess risk to human health (AENV 2006c). The protozoan parasites Giardia and Cryptosporidium are a particular concern in southern Alberta (Koning et al. 2006), and some municipal water treatment plants in southern Alberta do monitor for these in raw water prior to treatment. Members of two bacteria groups, coliforms and faecal streptococci, are used as indicators of possible faecal contamination because they are commonly found in human and animal faeces (Mackie 2001). Not all bacteria in these groups are harmful to humans, but their presence indicates harmful, disease-causing bacteria and protozoa may be present due to faecal contamination. The most commonly tested faecal

bacteria indicators are total coliforms, faecal coliforms, *E. coli*, faecal streptococci, and enterococci. Total coliforms include bacteria found in animal faeces, but also bacteria that naturally occur in the soil and water. This means they do not just indicate faecal contamination, which is the primary concern for human uses of untreated surface water, and are more useful as a general indicator of contamination after drinking water has been treated. Although faecal coliforms are a subset of total coliform bacteria and better represent faecal contamination, not all bacteria in this group cause gastrointestinal illness in humans. Therefore, *E. coli* and enterococci are now accepted as the best indicators of the human health risk from contact or consumption of untreated surface water (US EPA 1997). *E. coli* is a species of faecal coliform bacteria that is specific to human and other warm-blooded animal waste. Enterococci are a subgroup of faecal streptococci, which are commonly found in the digestive systems of humans and warm-blooded animals and these bacteria are more human-specific and may provide a higher correlation with many human pathogens than faecal coliforms. As a result, the United States Environmental Protection Agency (US EPA) recently decided to replace total faecal coliforms with Enterococci as the new federal standard for water quality at public beaches (US EPA 2004). Faecal coliforms, *E. coli*, and enterococci are all relevant indicators for contamination of surface waters in southern Alberta with human pathogens (Table 5), and the indicator or indicators that are most appropriate to monitor will depend on the specific concerns in individual watersheds.



Surface runoff from a parking lot carrying oil with it

Road salt application

There are countless other substances that can contaminate water beside those discussed in this report. The chemical pollutants of greatest concern are those that are widespread and persistent in the environment, can accumulate in biological tissues and be biomagnified by food chains, and cause harmful biological effects at extremely low concentrations. These include pesticides, pharmaceuticals, organochlorines, metals like mercury, non-metals like selenium, road salt, and hydrocarbons. Many of these chemicals are often found at low concentrations at which the consequences to the environment and human health is unknown. The potential for these chemicals to have synergistic effects and interactions in the environment further complicates their evaluation. Although these substances can be a serious concern, monitoring a comprehensive suit of chemicals throughout entire watersheds is unrealistic given the large number of potentially harmful substances that exist.

Pestiside use

Alberta Environment is monitoring key chemical pollutants at its Long Term River Network (LTRN) sites, and it is felt that biological indicators of aquatic and riparian ecosystem health should be monitored at these and as well as other sites throughout watersheds to assess the cumulative effect of chemical pollutants.

2.3.1 Water quality condition and pressure indicators

All of the water quality parameters reviewed in this report, including man-made or toxic pollutants as well as natural water quality parameters, can be used as indicators and classified as being either condition or pressure-type indicators. ***Condition indicators are measurements of water quality parameters taken anywhere in the drainage system of a watershed including reservoirs, lakes, rivers, streams, and wetlands (Table 5)***. These measurements can be affected by many different human activities as well as natural processes, and distinguishing between human impacts and natural factors is important for understanding the cause of water quality impairment. There have been enough studies measuring ambient water quality in relation to requirements needed for human use and protection of aquatic life that a variety of agencies have developed threshold values to define limits on where water quality indicators should lie (Table 5). The Canadian Council of Ministers of the Environment has established guidelines (CCME 1999), as has the US EPA (2002), and many of the Alberta Environment's Surface Water Quality Guidelines for protection of aquatic life, irrigation and stock watering, and recreational use and aesthetics have been adopted from these federal guidelines (AENV 1999). However, although threshold values for many of the water quality indicators proposed in this report have been set either in Alberta or other jurisdictions, they still may not be able to be used across entire watersheds in southern Alberta. This is because water quality naturally varies in Alberta from cold, clear, nutrient-poor waters in the mountains to warm, turbid, nutrient-rich waters on the prairies. For some water quality

Water sampling from an irrigation canal

indicators more conservative and protective thresholds than what is currently set by the provincial guidelines are needed in the headwaters, while for other water quality indicators more lenient and permissive thresholds than what has been set under the current guidelines are needed in the prairies because these thresholds are exceeded under natural conditions. Ultimately, reach-specific or at least eco-region specific, water quality thresholds are needed (Table 5).

Pressure-type water quality indicators are different from condition-type indicators because they are only measured in effluent released by point sources such as municipal and industrial wastewater facilities (Table 6). When these indicators are used together with watershed scale water quality models, the measurements of effluent loadings can be used to calculate the contribution of point sources to the total amount of contamination being releasing into watersheds. For example, in terms of sediment loadings, a watershed scale water quality model could be used to

Cold, clear, nutrient-poor water

Warm, turbid, nutrient-rich water

Automated water sampler

estimate loadings from urban stormwater as well as from all human-disturbed land throughout entire watersheds using model-predicted soil erosion rates, a land quality condition indicator (see Table 1). Comparisons could then be made to total loadings from municipal and industrial wastewater, water quality pressure indicators (see Table 6), so that resources could be focused on improving the management of the largest contributors of suspended sediment to the watershed. Some continuous release wastewater facilities do have licensed limits on the concentration of certain water quality contaminants that can exist in the effluent released (AENV 2006c, see *Alberta Environmental Protection and Enhancement Act*), and beyond comparisons of these loadings with respect to non-point source loadings, municipal and industrial loadings should also be reported with respect to these limits.

POINT SOURCE LOADINGS ARE A DIRECT RESULT OF THE LEVEL OF TREATMENT THE EFFLUENT RECEIVES AND THE VOLUME OF EFFLUENT RELEASED.

Table 6. Water quality pressure indicators measuring municipal and industrial wastewater loadings.

Water quality pressure indicators	*Assessment role of the indicator*	*Indicator response to human activities & management actions*	*Potential or existing targets & thresholds used for the indicator*	*How indicator could direct management actions*	*Area indicator represents or density of sampling sites required*	*Temporal period indicator represents or frequency of sampling required*	*Cost & ease of sampling*
Wastewater loadings • municipal • industrial	Identify relative contribution of wastewater to the rivers' nutrient loads, oxygen demands, & pathogen levels.	Loadings are a direct response to level of treatment & volume of effluent released.	Total loading wastewater thresholds exist only for Calgary (just for TP & TSS), but could compare other municipal & industrial loadings with licence requirements & targets could be set to reduce loadings. Each facility also has a maximum capacity (volume), which acts as an operational threshold.	Sources contributing significant loadings to a river could be targeted for a higher level of treatment, reduced effluent volume, & more complete monitoring & reporting. Knowing loadings relative to thresholds/ targets would help when evaluating loading management options. Data could be used for watershed-level water quality modelling.	Wastewater loadings represent point sources of pollution.	Required frequency of sampling wastewater quality is outlined in each facility's approval. Continuous or daily composite samples are required from continuous release facilities.	Wastewater quality is already being sampled.

Calgary wastewater treatment plant

2.4 Aquatic and riparian ecosystems

Riparian and wetland area, Weaselhead Natural Environment Park, Elbow River and Glenmore Reservoir, Calgary

Indicators in the three areas of the environment considered in this report so far (land, water quantity, and water quality) are important factors affecting aquatic and riparian ecosystems. However, the processes linking human land use and the resulting land condition, flow regimes, and water quality to the condition of aquatic and riparian ecosystems are generally poorly understood or too complex to quantify. All of the parameters that affect biological organisms cannot be measured, and even if this was possible, guideline or threshold values exist for only some parameters and do not evaluate the cumulative effect of all of the factors affecting ecosystem health. ***Therefore, biological indicators of aquatic and riparian ecosystems are important because they provide a cumulative assessment of environmental performance by integrating over the long-term the effects of all sources of environmental stress involving land use and changes to water quantity and quality (Burcher et al. 2007, Adams 2002).***

Ecosystem health is a useful concept to describe the desired state of the environment because "health" is a condition that humans can intuitively understand. We commonly define health as the ability to respond to pressures and effectively restore and sustain some state of balance. However, despite our general understanding of what health means, defining ecosystem health in precise scientific terms is difficult. Two distinct approaches have been taken by environmental scientists and managers, one defining ecosystem health or integrity based on the ecological conditions observed in a pristine, undisturbed natural environment (Karr 1996); the other defining health in terms of the ability of the environment to provide goods and services to humans (Jacques Whitford 2005). Goods are things such as potable water, edible fish and wildlife, safe recreational opportunities, and adequate water for irrigation, stock watering, recreation, and commercial and industrial processing. Services are things such as flood protection, filtering of pollutants, and the maintenance of a liveable climate and aesthetically pleasing landscapes. To address the outcome of healthy aquatic ecosystems in the *Water for Life* strategy (AENV 2003), a working definition of aquatic ecosystem health was developed combining the ecological and human goods and services perspectives (North/South Consultants 2007): ***"A healthy aquatic ecosystem is sustainable and resilient to stress. It maintains its ecological structure and function over time similar to the natural (undisturbed) ecosystems of the region, and provides an array of unimpaired ecological services that continue to meet social needs and expectations." (Stantec 2005)***

This definition can also be applied to healthy riparian areas, which may be considered a component of aquatic ecosystem health. As watershed scale monitoring programs are developed in southern Alberta, more explicit eco-region or reach-specific outcomes addressing aquatic ecosystem health will be needed together with appropriate biological indicators to assess these outcomes. In southern Alberta ecosystem health and associated outcomes are likely to be defined more from an ecological integrity perspective in less disturbed headwaters regions, while the focus may be more on the goods and services the environment provides to humans in the lower reaches of watersheds where land use intensity increases.

There are many indicators to assess aquatic and riparian ecosystem health. Work is just beginning in Alberta to develop an environmental monitoring program that will encompass indicators to evaluate ecosystem health at the watershed scale (AENV 2006b), and the WPACs and WSGs should look to agencies tasked with managing aquatic and riparian ecosystems for direction. Regardless of which perspective is used in specific sub-watersheds or reaches to define health, for the purposes of this report indicators of aquatic and riparian ecosystem health (Table 7) have been classified into two groups:

- individual indicator species
- integrated multi-species measures

2.4.1 Individual indicator species

Individual indicator species are species that show a known response (either positive or negative) to environmental stress. Their response is similar to that of other species with similar ecological requirements and may be indicative of broader environmental conditions within an area, the presence and extent of human impacts, or the diversity of other species (Niemi and McDonald 2004).

Common measurements used to evaluate various types of indicator species include:

- presence/absence
- abundance or biomass
- spatial distribution
- size and age distribution
- condition factor
- survival or harvest rates
- reproductive effort and success


Bull Trout

Some species are used as indicators because when they are conserved a whole community of co-occurring species will also be protected (Carignan and Villard 2002). These species are often referred to as umbrella species because they have an overlapping geographical distribution with the other species they are intended to provide protection to (Fleishman et al. 2000). For example, bull trout have been used as an umbrella species by the US Fish and Wildlife Service in Habitat Conservation Plans designed to protect 17 species and stocks of native fish in Montana, Idaho, and Washington (USFWS and NMFS 2000). Watersheds containing areas known to be important for bull trout spawning and rearing have been given a higher classification for protection and are subject to less riparian forest logging than areas with a lower classification (Hitt and Frissell 2004).

Animals that have difficulty moving through areas that have been degraded by human land use can also be used as indicators of habitat connectivity because they have a limited ability (or high mortality risk) to move from one habitat patch to another (Carignan and Villard 2002). For example, trout populations that spend most of their lives in larger streams and rivers, but use small streams for spawning and nursery areas, may be affected by dams and stream crossings that make it difficult or impossible for fish to access these critical habitats. Therefore, successful spawning of these species in headwater areas may be a good indicator of connectivity with downstream ecosystems.


Bull trout spawning site (redds)

Species that rely on infrequent reoccurring environmental processes like floods and fires can also be used as indicators to assess whether these events are occurring frequently enough within an ecosystem. For example, cottonwood recruitment in riparian areas of rivers in southern Alberta requires both spring flooding to scour river banks creating bare ground suitable for seedling establishment as well as gradually decreasing flows to allow seedling roots to grow within a receding band of moist soil (Mahoney and Rood 1998). Because many other types of riparian vegetation also rely on these physical processes, cottonwood recruitment can be used as a general indicator of the health of riparian ecosystems in prairie regions (Dykaar and Wigington 2000).


Hanging culvert preventing fish passage

Other species that can be used as indicators may be non-native, invasive species that thrive in stressed or disturbed


Healthy stand of cottonwoods with young trees ready to replace older trees

Table 7. Examples of indicators of aquatic and riparian ecosystem health.

	Individual indicator species	*Integrated multi-species measures*
Condition indicators	• Presence, absence, and condition of umbrella species • Presence, absence, and condition of species with limited dispersal • Presence, absence, and condition of species that depend on environmental processes to reproduce (e.g., cottonwoods and floods)	• Single-metric measures of community diversity (e.g., number of species or families) • Multi-metric indices (e.g., biotic indices, Index of Biotic Integrity)
Pressure indicators	• Presence, absence, and distribution of non-native, invasive species that thrive in disturbed ecosystems • Harvest rates (i.e., angling and hunting) of indicator species	• Single-metric measures of community evenness (i.e., an evenness index) • Number of species tolerant to environmental stress present


Brook trout, an introduced and invasive fish in some parts of southern Alberta


Canada thistle, an invasive weed

ecosystems. For example, the distribution of non-native fish species in a watershed and measures of their abundance and biomass have been found to be related to riparian degradation, water quality, and surrounding land use (Kennard et al. 2005). However, caution should be exercised when using non-native, invasive species as indicators, because they may be present due to confounding factors related to local introduction and not always the result of human disturbances to the environment.

2.4.2 Integrated multi-species measures

Ecological communities are groups of organisms that have similar body size, that use similar types of habitat or food, or that share a common scientific classification (e.g., species or families). Communities are the basic building blocks of ecosystems, so effects shown at the community level can be easily extrapolated to entire ecosystems. ***Integrated multi-species measures examine diversity within biological communities using various community descriptors and can be used to determine the effects of disturbances on the larger ecosystem as a whole (Attrill 2002)***. The assumption behind these measures is that ecosystems that have not been degraded by human activities should have a high number of species or families present, an even distribution of individuals among the groups, and a moderate to high overall abundance of organisms (Metcalfe 1989). In aquatic environments stressed by organic pollution (e.g., nutrient inputs), communities are expected to respond with a decrease in diversity as sensitive organisms are lost, an increase in abundance as the tolerant organisms now have an enriched food source, and an overall decrease in evenness of the distribution of individuals among the different groups (Metcalfe 1989). A similar loss of diversity and


Healthy riparian area


Erosion in unhealthy riparian area

increase in abundance of non-native plant species is also expected in riparian environments subject to human land use disturbance such as overgrazing, stream crossings, and linear development (Maskell et al. 2006).

There are two general approaches to describing communities: single-metric community descriptors and multi-metric indices. Single-metric community descriptors are measurable aspects of biological systems that are known to change in a predictable fashion along a gradient of human impact (Verdonschot and Moog 2006). Common single-metric community descriptors can be broken down into four groups of indicators:

- number of various species or families (i.e., richness and composition)
- number of species at different levels of the food chain (i.e., trophic composition)
- number of species tolerant or sensitive to stresses (i.e., environmental tolerance or sensitivity)
- number and health of the organisms (i.e., abundance and condition)


Young northern pike

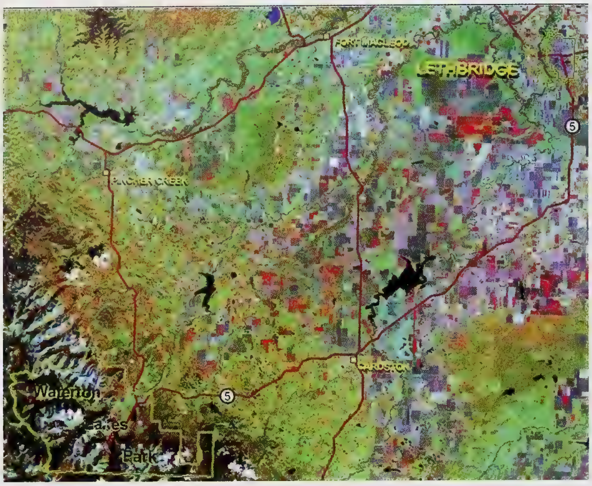
Beyond these basic indicators, which can be used independently as simple diagnostic features of human impacts on aquatic and riparian ecosystems, a variety of multi-metric indices for assessing biological data have also been developed. Examples include the Index of Biotic Integrity (Karr 1981), which has since been adapted for use worldwide, the Invertebrate Community Index (Verdonschot and Moog 2006); the US EPA Rapid Bioassessment Protocols for benthic invertebrate assemblages (Mackie 2001), and the Benthic Index of Biotic Integrity (Kerans and Karr 1994). ***These indices make use of the single-metric community descriptors described above, that individually provide information on a variety of ecosystem characteristics, by combining them into a numerical value or score, which functions as an overall indicator of biological condition. (Verdonschot and Moog 2006)***. Relative values for each single metric measured at human disturbed sites are determined based on a comparison with values observed in the best available habitat (least disturbed condition), and these relative values are then aggregated into a single number. It is this consolidation of information that is the real advantage of multi-metric indices. They are able to bring together large amounts of ecological data into a single index value, making it possible for the public and managers that lack a scientific background to see the relative levels of aquatic and riparian ecosystem health across watersheds (Yoder and Rankin 1999).

Historically, benthic invertebrates and fish have been most commonly used in multi-species measures of aquatic ecosystem health (Attrill 2002), although other communities of organisms that have varying tolerances to environmental stress and are representative of the larger ecosystem as a whole can also be used (e.g., algae, Griffith et al. 2005; zooplankton, Kane 2004; wetland plants, Miller et al. 2006; amphibians and riparian birds, Brooks et al. 1998). Benthic invertebrates are particularly useful because they can almost always be found in aquatic environments and have a wide range of sensitivities to environmental stress (Weiss and Reice 2005). However, using multiple types of organisms can be valuable because they each will reflect environmental stresses and the associated effects on ecosystem health in different ways (Griffith et al. 2005).

Although multi-metric indices have been developed throughout North America, some ecoregion-specific tailoring of these indices will be necessary to account for the high physical, chemical, and biological variability seen between and within watersheds in southern Alberta. One key consideration when using multi-species metrics or indices to assess aquatic and riparian ecosystem health is the use of reference sites. These sites are needed to define the metric and index values that would be expected throughout the ecoregion or subwatershed being sampled in the absence of human disturbance (Fore 2003). In other words, reference sites approximate what the rest of the sampled sites would have looked like if they were not impacted by human activities, and comparisons between observed and expected conditions at these sites can be made to estimate overall ecosystem health.


Benthic invertebrates

3.0 Indicator Monitoring



Designing and implementing an integrated monitoring program for all of the indicators in the four areas of the environment considered in this report (land, water quantity, water quality, and aquatic and riparian ecosystem health) represents a significant challenge to overcome. Of all the monitoring required, data currently being collected on land use pressure indicators (Table 2) and water quantity condition indicators (Table 3) come closest to meeting the requirements laid out in this report. A vast amount of land use data is already being collected from aerial or satellite imagery for databases maintained by provincial and municipal agencies and directly from watersheds through 'on-the-ground' censuses and surveys. These data could be used to measure or estimate the relevant aspects of the human footprint on the landscape that have been proposed as indicators (Table 2), and existing monitoring programs can be expanded to fill data gaps. In terms of water quantity, a comprehensive network of stream and river flow gauging stations already exists across southern Alberta. For indicators like non-point source loadings that require modelling at the watershed scale (soil erosion rates, see Table 1; runoff rates and volumes, see Table 4), the appropriate agencies (Alberta Environment, Alberta Agriculture and Food, Alberta Sustainable Resource Development, municipal governments) are in the process of developing the technical expertise and human resources to do the appropriate modelling. This is the primary factor inhibiting these indicators from being monitored and evaluated under existing and changing land use scenarios. In terms of monitoring the volume, rate, and timing of licensed water diversions and return flows (Table 4) and municipal and industrial wastewater loadings (Table 6), some monitoring is already occurring, and expanding this monitoring is an ongoing and relatively straightforward process.

Water Survey of Canada stream gauging station measuring river discharge

The remaining indicators for which monitoring and data availability have not been discussed are vegetation-based land quality on public and private rangelands and riparian areas (Table 1), ambient water quality with respect to all applicable designated uses (Table 5), and aquatic and riparian ecosystem health (Table 7). Currently in southern Alberta, data on these indicators is geographically patchy or very limited and accurate watershed scale assessments are not possible. So clearly, the largest task at hand is to develop a monitoring program that would provide an integrated watershed scale evaluation of land quality, water quality, and aquatic and riparian ecosystem health. Because of the importance of evaluating biological indicators, efforts are being made in Alberta to develop a more holistic water quality monitoring program that encompasses aquatic and riparian ecosystem health (AENV 2002, 2006b). The broad variability in water quality and ecosystem types across southern Alberta and the fact that many different agencies are involved in managing land, water, and aquatic and riparian ecosystems, means that such a program will need to be developed collaboratively. Designing a monitoring program should therefore be done in cooperation. The goals of this program should be to:

1. Estimate the current status, trends, and changes in the proposed vegetation-based land quality, ambient water quality, and aquatic and riparian ecosystem indicators at the watershed scale with known statistical confidence,
2. Estimate the distribution and quality of the resources these indicators evaluate across watersheds (e.g., areal proportion of open water in a watershed with a nitrate concentration > 1.0 mg/L),

Rangeland vegetation diversity

Riparian area in a coulee

Healthy aquatic ecosystem

Water quality sampling

3. Evaluate whether any associations exist between these condition indicators and human environmental disturbances, and
4. Provide regular (e.g., annual) statistical summaries and assessments of environmental performance relative to the relevant watershed outcomes.

In order to meet these goals, a consistent, unbiased method of estimating the condition of rangeland, riparian, and aquatic ecosystems distributed across entire watersheds is required. This program will need to outline how the data that is collected will be applied to the larger region it is meant to represent (i.e., a subwatershed or watershed). Lack of such a program was identified as a key impediment to aquatic ecosystem health assessment in the recent evaluation of existing provincial water quality, sediment quality, and non-fish biota data conducted for Alberta Environment under the *Water for Life* strategy (North/South Consultants 2007).

There are two distinct approaches to selecting sampling sites for evaluating status and trends across watersheds (Stevens 1994). These approaches are based on very different perceptions of regional evaluations, and lead to correspondingly different methods for making regional inferences. In one approach, sites are selected based on their anticipated ability to reflect regional characteristics. Factors considered in site selection may be regional spatial patterns in physical, chemical, and biological characteristics and changes in the types and intensities of land use, expected sensitivity to these land uses, and the anticipated level of exposure the site receives to the known or suspected environmental stresses. For example, the Alberta Environmentally Sustainable Agriculture program monitors water quality in 23 small agricultural watersheds selected on the basis of a suite of agricultural variables addressing livestock and cropping as well as on factors such as soil types and erosion rates (Anderson et al. 1999). The watersheds were selected to represent the broad range of agricultural intensities throughout Alberta (North/South Consultants 2007).

The other approach is statistical and a probability sample of sites to be evaluated is selected once the entire population of potential sampling sites has been explicitly defined. Every element of the population of potential sampling sites has some chance of being sampled, and the selection of sites is carried out by a process involving an explicit random element. In order to evaluate the condition of the land, ambient water quality, and aquatic and riparian ecosystem health across entire watersheds with known confidence, the statistical approach must be used (Stevens 1994). Sampling sites can still be unevenly

allocated across stratified regions within watersheds by adjusting the probability of including a subset of sites to focus sampling on specific areas (Schweiger et al. 2005). If the alternative targeted sampling approach is used, the condition of the samples is not representative of the entire watershed because not all sampling sites have the potential to be sampled and thereby influence the estimates of environmental condition.

Despite the importance of the probability-based approach for regional assessments, the WPACs and WSGs should be aware that no single sampling methodology can fully encompass the hierarchy of spatial scales involved in assessing the environmental condition of land, water, and aquatic and riparian ecosystems. Assessments can be done at spatial scales ranging from watersheds and sub-watersheds, down to reaches, sites, and individual habitat elements (Figure 4). The WPACs and WSGs will need to select a number of assessment techniques that will be conducted on several spatial scales and can be integrated to provide an overall assessment of these resources in their watersheds relative to the outcomes they have defined. Their work should begin at the largest spatial scale of assessment relying on existing information and remote or areal sampling techniques and progress towards finer scales where field based surveys will be required to sample small scale variables. This will be difficult because many assessment techniques that are commonly used are conducted at small, site-specific spatial scales, even though the pressures affecting conditions at these smaller scales are often related to environmental pressures operating at the reach, subwatershed, or watershed scales (Fausch et al. 2002).

Beyond the various types of sampling approaches that can be taken, there are some other important factors to consider when designing a monitoring program for water quality, land quality, and aquatic and riparian ecosystem health. The amount of time that can be left between consecutive sampling of indicators for these environmental components depends on a number of things including the specific parameter being considered, the time of year at which the sampling is occurring, and the location where the sampling is occurring. Indicators of rangeland quality and riparian health would likely only need to be monitored every three

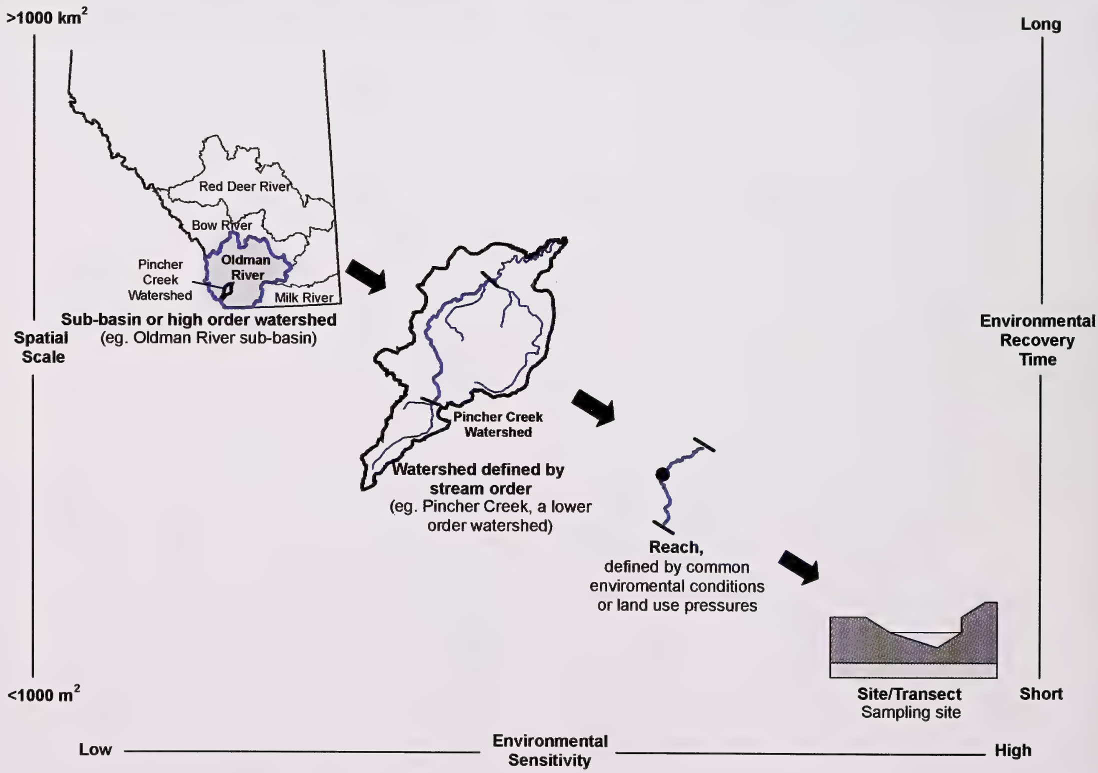


Figure 4. The range of spatial scales over which watershed assessments can occur, and how the sensitivity of environmental conditions to human pressures and the recovery time required following environmental degradation are both affected by spatial scale (adapted from Fausch et al. 2002).

to five years, depending on the specific indicator and changes in land management practices (Adams et al. 2005, Fitch at al. 2001). Aquatic ecosystem health indicators may need to be sampled annually or bi-annually as populations of aquatic organisms can change significantly from year-to-year. In terms of water quality, it can improve or deteriorate at a single location and sometimes the changes can be very rapid. This means a single water quality measurement

may only represent what the water quality was at the time it was taken (like a snap shot in time). As a result, water quality indicators generally need to be measured frequently (Table 5): at least monthly, but often bi-weekly, daily, or continuously (Cavanagh et al. 1998). Parameters such as temperature and dissolved oxygen may show diurnal cycling and can also be dependent on changes in flow (Figure 5). As a result, dissolved oxygen and temperature should be measured on a continuous basis in areas where they may

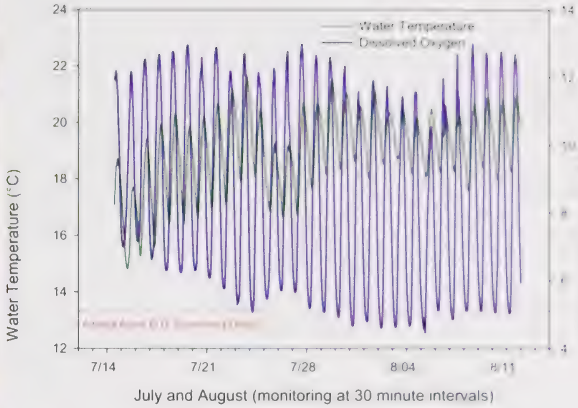


Figure 5. Diurnal cycling of temperature and dissolved oxygen in the Bow River just downstream of the City of Calgary limits (Stiers Ranch) in 2003.

be jeopardising a designated water use (Table 5). Sampling frequency for water quality indicators may also need to be increased during critical periods in order to capture important changes in indicator values (Cavanagh et al. 1998, see Table 5). These periods could be during the spring snowmelt, storm events, low-flow periods, or when humans or aquatic life depend on high water quality (e.g. contact recreation, irrigation, spawning and emergence). Outside of these critical periods, sampling may be less frequent for some water quality indicators like total suspended solids because they reflect more stable processes.

Cutline, West Prairie Creek

FOR ALL INDICATORS OF WATER QUALITY, LAND QUALITY, AND AQUATIC AND RIPARIAN ECOSYSTEM HEALTH, SAMPLING FREQUENCIES AND THE DENSITY OF SAMPLING SITES MAY BE LOWER IN CERTAIN AREAS OF A WATERSHED THAT ARE LESS DISTURBED (I.E., THE HEADWATERS).

Generally in southern Alberta, conditions for these components of the environment decrease with distance downstream from the headwaters due to an increase in land use intensity from west to east, and monitoring programs should account for this variation. For example, in terms of water quality, nutrient levels in headwater streams may not change rapidly but downstream from major cities changes could occur daily as the volume of municipal wastewater effluent changes, requiring continuous sampling. In terms of rangeland quality, livestock grazing intensities are already known on public land in the Forestry Reserve so fewer sampling sites could be used than on private land. Cooperation between WPAC and WSG stakeholders and member agencies will be critical for implementing an integrated sampling program with adequate sampling frequencies and densities to detect significant spatial and temporal changes in water quality, rangeland quality, and aquatic and riparian ecosystem health.

Electrofishing

4.0 Data availability

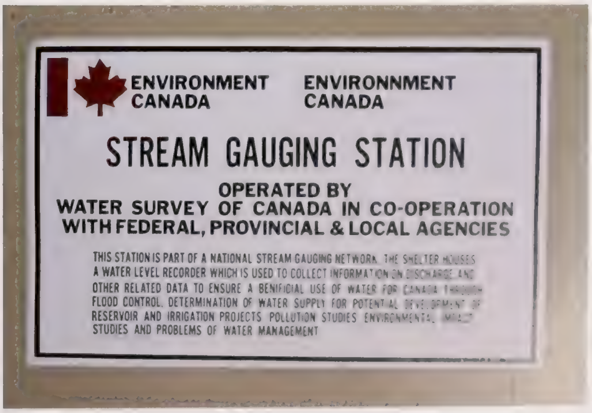
The WPACs and WSGs will face a significant challenge to monitor some of the indicators proposed in this report. Indicators have been proposed based on a thorough evaluation of the systems involved in affecting watershed conditions rather than on the basis of what data are available to support their selection. In terms of land cover, although extensive datasets exist, they are often not up-to-date and information on different components of the cumulative human footprint are collected by many different agencies, kept in different formats, and updated at different frequencies. In spite of these difficulties, there are two datasets that will be particularly relevant to addressing land use:

- Alberta Sustainable Resource Development together with Alberta Environment is currently undertaking a four-year project, the Grasslands Vegetation Inventory (GVI), to collect data on natural and human land cover types and constructed landscape features for the prairie region of southern Alberta within the Bow, Oldman, South Saskatchewan, and Milk River watersheds (McNeil et al. 2006). These data, collected from aerial photography, will be vital to enabling the WPACs and WSGs to begin understanding the overall impacts of land use on their watersheds.
- A similar inventory, the Alberta Vegetation Inventory (AVI) has been maintained for the forested portion of the province by Alberta Sustainable Resource Development and the forestry industry since 1987 with regularly scheduled updates (Nesby 1997).

Data from a variety of other spatial databases held by the Energy and Utilities Board, Alberta Infrastructure and Transportation, municipalities, academic researchers, and environmental non-governmental organizations can also be used to measure elements of the human footprint. Statistics Canada's population and agriculture censuses, municipal censuses, and crop insurance data, and various pesticide sales databases can be used to monitor human population and dwelling unit density and amounts of agricultural and non-agricultural fertilizers and pesticides applied to the land.

GVI and AVI will provide some basic information for measuring land quality in terms of estimates of the amount of the land base covered in natural vegetation including wetlands and riparian areas. Soil erosion modelling done by Alberta Agriculture and Food provides estimates of erosion rates for all of the soil polygons in the Agricultural Region of Alberta Soil Inventory Database (Jedrych and Martin 2006), although these rates have only been simulated under a uniform land use scenario of summer fallow (bare ground). Future work could model erosion rates under current land use scenarios. However, beyond GVI, AVI, and Alberta Agriculture and Food's spatial databases, there is very little site-specific data on land quality in southern Alberta that can be extrapolated to the watershed scale. Alberta Sustainable Resource Development does have some benchmark plots to assess rangeland quality, but these only exist on public lands and are too scarce to represent the overall condition of rangelands across entire watersheds. The Alberta Biodiversity Monitoring Institute (ABMI) will collect some data relevant to land condition in terms of soil quality and the amount of human caused bare ground (Stadt et al. 2006). However, of 1,656 National Forest Inventory sites evenly spaced 20 km apart across Alberta, only 375 will be sampled each year with each site being sampled every 5 years, and this will not provide adequate representation of land quality for individual watersheds. The WPACs and WSGs could, however, partner with the ABMI monitoring program to sample additional randomly selected sites in their watersheds for greater representation.

In terms of water quantity, Alberta Environment already has the capacity to estimate the condition indicators proposed in this report based on deviations of the recorded flow regime from naturalized flows, IFN values, WCOs defined in the SSRB Watershed Management Plan, and Instream Objectives. Estimates can be made at gauging stations throughout watersheds, and as more water use data is collected the accuracy of these estimates will improve with the accuracy of the naturalized flow estimates. Data on the water quantity pressure indicator measuring all licensed water diversions and the associated return flows is being collected and reported to Alberta Environment for many of the larger water users, including municipalities



and irrigation districts. However, these data are not always reported in electronic format, and incentives may be required to collect water use information from smaller water users. A pilot project organized by Alberta Environment and Alberta Agriculture and Food is currently being conducted on the Milk River to report near real-time water use of private irrigators along the mainstem, and similar projects may provide water use data in other basins in southern Alberta (Personal Communication Werner Herrera, AENV). Accurate land cover data and improved modelling capacity will be required before changes to runoff rates and volumes for all human-disturbed lands throughout entire watersheds can be used as a water quantity pressure indicator at the watershed scale. In addition, monitoring changes to the magnitude and frequency of base and peak flow events in small watersheds where natural land cover has been altered may require new flow gauging stations to be installed.

In terms of water quality, data on ambient water quality condition indicators are being collected by Alberta Environment and Alberta Agriculture and Food at key locations on the mainstem rivers and in the tributaries and reservoirs on a rotating or case-specific basis. However, rigorous sampling programs will need to be designed and implemented to accurately determine whether water quality meets the requirements for all designated uses across entire watersheds. Some data on water quality pressure indicators is being collected, since all wastewater facilities licensed under the *Alberta Environmental Protection and Enhancement Act* have some monitoring requirements (AENV 2006c).

In terms of riparian health, Cows and Fish conducts riparian health assessments and inventories throughout southern Alberta (Cows and Fish 2007). However, these riparian assessments and inventories are only conducted with landowners' permission, and therefore, only a small and unevenly distributed proportion of the total riparian area in southern Alberta has been examined.

Cows and Fish riparian assessment

5.0 Conclusion

Castle River fish sampling (electrofishing)

Data coming from monitoring the indicators proposed in this report should be used by the management agencies and stakeholders taking an active role in the work of the WPACs and WSGs to report on the state of their watersheds and develop watershed management plans that integrate the effects of land use and land quality on water quantity, water quality, and aquatic and riparian ecosystem health. This integration is important because, although these environmental components are intimately connected, there has traditionally been a disconnect between efforts to improve water supply, water quality, and aquatic and riparian ecosystem health and efforts to manage land use activities (Wang 2001). The ability of the WPACs and WSGs to coordinate these activities will be critical for effective watershed management, and a concerted and cooperative effort from government, industry, academia, conservation groups, and agricultural stakeholders will be necessary.

Currently, managing water quantity and quality is largely the responsibility of Alberta Environment and to some extent, Alberta Agriculture and Food; municipal governments are in charge of land-use planning at the local level, and Alberta Sustainable Resource Development manages public land inside and outside of the Forestry Reserve. Responsibility for healthy aquatic and riparian ecosystems is shared by two government agencies (Alberta Sustainable Resource Development and Alberta Environment) and two non-government agencies (the Alberta Conservation Association and Cows and Fish). Alberta Environment primarily manages point sources of water pollution that have been identified as being a concern, and lacks the authority to control non-point sources of pollution, which are now cumulatively leading to water quality problems. At the same time, land-use plans only serve the jurisdiction that adopts them, and water quality over the broader watershed beyond the political boundaries of the plan is generally not considered. The WPACs and WSGs have the opportunity to address the overall lack of coordination in managing environmental performance from a watershed perspective by linking values or trends they observe in the water quantity, water quality, and aquatic and riparian ecosystem indicators they monitor to corresponding patterns observed in land use and land quality. Based on relationships they observe, they can then make some specific recommendations to both municipal and provincial agencies on ways to improve environmental performance.

6.0 Glossary

Alluvial groundwater
Groundwater that exists in the porous sand and gravel beneath and beside streams and rivers. Alluvial groundwater is constantly contributing to the surface water flowing down streams and rivers and vice versa.

Atmospheric deposition
The process in which precipitation (rain, snow, fog), airborne particulate material or liquid droplets, and gases move from the atmosphere to the earth's surface. Atmospheric deposition is an important way in which air pollutants reach the earth's surface through precipitation or as dry deposition. Atmospheric deposition of nutrients is an increasing problem, particularly as a source of excess nitrogen, and the process can also be a significant source of other toxic contaminants such as trace metals and organic compounds.

Base flow
Steady flows that remain in streams following storm events and periods of spring snowmelt. In unimpacted watersheds base flows are relatively high because they are maintained by slow surface runoff and substantial groundwater inputs to the stream.

Benthic invertebrates
Organisms that live on the bottom of a waterbody or among the debris or in the sediment. Aquatic insects, crayfish, snails, clams, worms, leeches, and mites are all included in this group. They are a critical component of aquatic food chains because they eat almost any form of organic material, ranging from bacteria, phytoplankton, and zooplankton to filamentous algae to larger aquatic plants and decaying plant material to other benthic invertebrates and larger dead animals. They are the major food source for many fish, waterfowl, and shorebirds.

Blooms
Relatively rapid increase in the population of algae or cyanobacteria in an aquatic system, usually as the result of an excess of phosphorus or nitrogen in the water. Often recognized by discoloration of the water resulting from the high density of pigmented cells. As the phytoplankton die, this dead organic matter becomes food for bacteria that decompose it, which uses up dissolved oxygen and can cause other forms of aquatic life to die.

Coliforms
Bacteria that are commonly used as a water quality indicator because they are abundant in the faeces of warm-blooded animals, although they can also be found in soil and on vegetation. In most instances, coliforms themselves do not cause illness, but their presence is used to indicate that other pathogenic organisms of faecal origin may be present. *E. coli* are coliform bacteria.

Communities
An assemblage of populations of different species interacting with one another. Communities can be defined based on similar body size, the use of similar types of habitat or food, or a common scientific classification.

Condition indicators
Biotic or abiotic characteristics in the environment that can provide an estimate of the quality of environmental resources with respect to human or ecological requirements.

Conservation tillage
A way of using specialised equipment to grow crops from year to year without having to till the soil to remove weeds, mix in manure and fertilizers, and prepare the surface for seeding.

Cryptosporidium
Single-celled pathogens that infect and inhabit the gastrointestinal tracts of a wide variety of domestic and wild animal species as well as humans. Several species of Cryptosporidium can infect humans and cause a diarrhoeal illness called cryptosporidiosis. Cryptosporidium are passed via the faecal-oral route when cysts are ingested via contaminated hands, food and/or water, or through person to person or person to animal contact. Because of resistance to chlorine, ultraviolet light and ozonation are becoming a common means of water treatment, although filtration can still be an effective means of removing a high percentage of pathogens.

Cumulative effects
Those changes to the environment caused by an activity in combination with other past, present, and reasonably foreseeable future human activities.

Cyanobacteria
A group of bacteria that obtain their energy through photosynthesis and are also referred to as blue-green algae, although they are not technically algae. In warm, nutrient-rich environments, cyanobacteria can grow quickly, creating blooms that spread across the water surface and may become visible. Some species of cyanobacteria produce toxins, making them dangerous to animals and humans.

Dissolved oxygen
A relative measure of the amount of oxygen dissolved in water taking into account the temperature of the water and the amount of dissolved material it contains. Dissolved oxygen is essential for almost all forms of aquatic life.

Disturbance-caused plants
Native or non-native plants that are well adapted to an environment of continual stress giving them a competitive advantage over other species associated with mature plant communities. Disturbance-caused plants are often found in areas where the land receives a high level of disturbance.

Ecosystem goods and services
Products that are made from the environment and used by humans and the environmental conditions and processes that sustain human life.

Ecosystem health
The ability of an ecosystem to sustain itself, be resilient to stress, maintain ecological structure and function that is similar to natural (undisturbed) ecosystems, and provide an array of unimpaired ecological services that meets social needs and expectations.

Ecosystems
Natural units consisting of all the plants, animals, and microorganisms in an area functioning together with all the nonliving physical and chemical factors of the environment.

Enterococci
A bacteria that is believed to provide a higher correlation than faecal coliforms with many of the human pathogens often found in human sewage.

Environmental indicators
Physical, chemical, and biological attributes or components of the environment that are quantifiable and play an important role in affecting environmental conditions or functions. Condition indicators measure biotic or abiotic characteristics in the environment and provide an estimate of the quality of environmental resources with respect to human or ecological requirement. Pressure indicators measure human activities that can affect important resources in the environment when their intensity or magnitude reaches a certain point.

Environmental outcomes
Specific conditions or functions that environmental users and managers would like from the environment.

***Escherichia coli* (*E. coli*)**
Coliform bacteria that are almost exclusively of faecal origin, so their presence in water is an effective indicator of faecal contamination. Most strains of *E. coli* are harmless and live in the intestines of healthy humans and animals, but the O157:H7 strain produces a powerful toxin and can cause severe illness.

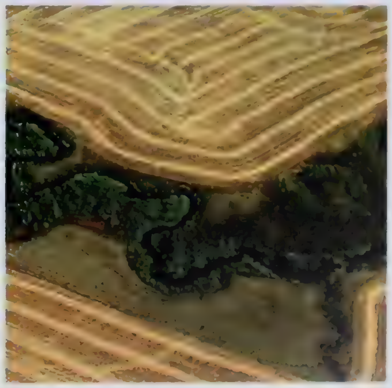
Eutrophication
The process of increased photosynthetic activity in an aquatic system. Carbon dioxide is used by aquatic plants to produce organic compounds. Eutrophication is caused by an increase in nutrients, typically nitrogen or phosphorus, and is characterised by high dissolved oxygen levels during the day resulting from photosynthesis and low dissolved oxygen levels during the night as plants stop photosynthesising and all aquatic life continues to use oxygen to provide energy for their cellular processes.

Evapotranspiration
An important part of the global cycling of water from land to air. The sum loss of water from vegetated land cover resulting from evaporation from the soil, canopy, and any surface water plus the loss of water directly from within plants as vapour is released through holes in the leaves.

Faecal streptococci
A group of bacteria naturally inhabiting the gut of warmblooded animals and humans and used as an indicator of faecal contamination.

Families
Units of biological classification of organisms, within which many species exist.

Flow regimes
Flow measured as the volume of water passing a given point in a stream or river at any given point in time (e.g., cubic meters per second). Flow regimes generally refer to the pattern of high and low flows that occur over the course of a full year.



Food chain
The hierarchical feeding relationships between species in an ecological community in which energy is transferred as material from one species to another.

Giardia
Single-celled pathogens that infect and inhabit the gastrointestinal tracts of a wide variety of domestic and wild animal species as well as humans and cause a diarrhoeal illness called giardiasis (also known as beaver fever). Several species of giardia can infect humans, but not all. Giardia are passed via the faecal-oral route when cysts are ingested via contaminated hands, food and/or water, or through person to person or person to animal contact. Because of resistance to chlorine based disinfectants, ultraviolet light and ozonation are becoming a common means of water treatment, although filtration can still be an effective means of removal.

Groundwater
Water located beneath the ground surface in soil pore spaces and in fractures of geologic formations. Groundwater is recharged from, and eventually flows to, the surface naturally through springs, streams, wetlands, rivers, or lakes.

Habitat
The place where an organism or population lives, and its surroundings, both living and nonliving. Habitat includes all life requirements such as food and water as well as the physical elements that make up an organism's living space.

Index
A synthesis of several indicators that are combined using a weighted-sums approach into an overall measure of status or quality of an environmental element.

Integrated Watershed Management Planning
A planning process that can be used to address multiple watershed outcomes simultaneously, whether those outcomes are to improve water quality for a particular human use, address water supply shortages for our growing population, or restore and maintain a valued component of aquatic or riparian ecosystems. An adaptive five-step environmental performance management system is used to address the outcomes and watershed management plans are prepared to geographically and numerically define desired environmental outcomes and associated indicators, thresholds, and targets together with a monitoring program and action plan for implementing the proposed outcomes.

Invasives
Introduced species that do not originally occur in the area of concern. They tend to spread widely throughout the new environment because there are few natural predators or other biological controls. In many cases they displace native species from their natural habitats and disrupt the environment because they do not perform the same ecological functions as the species they have replaced.

Land cover
The physical material on the land's surface including vegetation, water, bare rock and soil, as well as human constructed cover such as asphalt. Land cover is distinct from land use, which is a description of how humans utilise the land.

Land use
Any human use of land that alters the land from its natural state.

Loadings
A water quality term used to describe the amount of contaminants such as nutrients or sediment being released to a water body from point and non-point sources. Loadings are mass-based measurements (e.g., kg per day).

Native vegetation
Any species of vegetation that existed in the area of concern before European settlement, including trees, shrubs, and groundcover or wetland plants. Native vegetation does not include plants that originated from other parts of Canada or from other countries and did not previously exist here.

Natural flow regime
The characteristic variable and dynamic pattern of change in the quantity and timing of flows on an undammed (unregulated) stream or river.

Nitrogen
A key nutrient that can exist as ammonia (NH3), nitrate (NO3), and nitrite (NO2) in aquatic environments. Nitrate is an essential plant nutrient, but in excess amounts it can cause increases in aquatic plant growth, which in turn can lead to low dissolved oxygen and the death of certain invertebrates and fish. The natural levels of ammonia and nitrate in surface water are typically low, because they are quickly converted to nitrate.

Non-point sources
Sources of water quality contamination that can not be easily pinpointed to a single location because they occur over a wide area and are associated with particular land uses. Common non-point sources are agriculture, forestry, urban impervious surfaces, and mobile sources such as livestock and motorised vehicles.

Pathogens
Microorganisms (viruses, bacteria, and fungi) and some unicellular and multicellular parasites that have the ability to adversely affect human health in a variety of ways. These organisms are everywhere in the natural environment (e.g., water, soil, plants, and animals), but their abundance is generally low, posing minimal risk to humans. However, when human and domestic animal waste is released to the environment, this can increase the risk posed by these organisms.

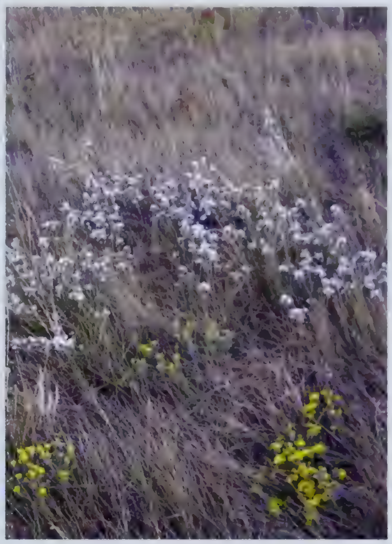
Peak flows
Large, infrequent flows characterised by a high volume of water discharged over a short period of time. In urban areas where impervious surfaces create high runoff rates and volumes peak flows are more intense and can cause flooding and erosion problems.

Phosphorus
A key nutrient that is often in short supply in freshwater environments, and the availability of which can govern the rate of growth of many aquatic organisms. Even small increases in the amount of phosphorous can set off a chain of undesirable events including accelerated plant growth, algae blooms, low dissolved oxygen, and the death of certain invertebrates and fish. In nature, phosphorus usually exists as part of a phosphate molecule (PO4). Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, as in plant or animal tissue. Phosphate that is not associated with organic material is inorganic. Animals can use either organic or inorganic phosphate. Both organic and inorganic phosphorus can either be dissolved in the water or suspended (attached to particles in the water column). Dissolved inorganic phosphorus is the form required by plants.

Phytoplankton
Microscopic photosynthetic plants that are suspended in the water column and make up part of the planktonic community in aquatic environments.

Point sources
Sources of water quality contamination arising from effluent released from specific locations such as a municipal wastewater treatment plant or an industrial facility.

Pressure indicators
Measurements of human activities that can affect important resources in the environment when their intensity or magnitude reaches a certain point.



Rangeland
Land supporting indigenous or introduced vegetation that is either grazed or has the potential to be grazed. Rangeland includes grassland, grazeable forestland, shrubland, pastureland, and riparian areas.

Reference sites
Reference sites are places that show very little or no apparent disturbance from human activity, whether it be agriculture, industrial or urban development, or recreation. Reference sites provide an estimate for what aquatic and riparian ecosystems would look like at an impacted sampling site if there had been no human influences there.

Riparian
Used to describe the land at the interface with a surface water body, as well as the associated plants and animals that rely on the increased soil moisture and surface water.

Runoff
Water from rain, snowmelt, or other sources that flows over the land and drains into a surface waterbody rather than infiltrating into the ground.

Sediments
Unconsolidated rock particles created by weathering and erosion of the land and transported by water, wind, or glaciers.

Soil erosion rates
The mass of soil material lost to erosion from a given area of land over one year (e.g., 50 tonnes/hectare/year). Soil erosion rates can be estimated over a broader area using soil erosion models calibrated with sediment loads in the streams that drain the region.

Species
One of the basic units of biological classification of organisms. A group of individual organisms that are very similar in appearance, anatomy, physiology, and genetics because they share relatively recent common ancestors and are able to breed among themselves but not with members of another species.

State of the Watershed reporting
A key activity of the Watershed Planning and Advisory Councils under Alberta's *Water for Life* strategy. Involves reporting on the state of their watersheds on a regular basis. These reports focus on desired environmental outcomes and evaluate progress toward reaching these outcomes using related condition and pressure indicators.

Target
An indicator value that reflects a desirable environmental outcome.

Threshold
An indicator value that reflects a problematic environmental cond

Total suspended solids
A water quality measurement that is the dry-weight of particles suspended in the water that are trapped by a filter of a specified pore size.

Trihalomethanes
Compounds formed as a by-product when chlorine is used to disinfect water used for drinking. They result from the reaction of chlorine with microscopic organic material remaining in the water that is being treated. Trihalomethanes can have adverse health effects at high concentrations, and limits have been set on the amount permissible in drinking water.

Turbidity
A measure of the transparency of water to light, which depends on the amount of suspended solids in the water causing a cloudy or hazy appearance. If a relation between turbidity and total suspended solids can be developed for a specific stream, turbidity can be used as a surrogate measurement for total suspended solids.

Umbrella species
A species whose conservation is assumed to provide an 'umbrella' of protection for other species due to shared habitat requirements and spatial distributions.

Water for Life strategy
The Alberta government's long-term management strategy for addressing all water-related issues. The strategy arose from an understanding that it will be impossible to meet all current and future water quantity and quality demands while at the same time ensuring a sustainable economy, supporting a growing population, and securing healthy aquatic and riparian ecosystems. The variability of future water supply and quality related to the effects of climate change increases the level of uncertainty regarding whether these needs can be met. The strategy encourages an adaptive environmental performance management system that informs managers and the public about the condition of a watershed relative to what is desired and whether or not the things that are being done to manage environmental impacts are actually working.

Water table
The soil depth at which pore spaces become fully saturated with water.

Watershed Planning and Advisory Councils
Regional organisations working on a watershed scale to raise awareness of the state of Alberta's major river basins. Joining with governments and other stakeholders, these councils will participate in developing, implementing, and continuously monitoring and revising water and watershed management plans.

Watershed Stewardship Groups
Sub-regional organisations working on a watershed scale at the community level raising awareness and undertaking 'on the ground' activities to protect and enhance local water bodies. These groups deliver knowledge and best management practices to landholders that are making improvements to the water in their watersheds.

Watersheds
Regions of land where water from rain or snow melt drains downhill into a body of water, such as a stream, wetland, river, lake, or reservoir. Watersheds include both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels. The land acts as a drainage basin funnelling all the surface water within the area covered by the basin and channelling it into a waterway. Each watershed is separated from adjacent watersheds by ridges of high ground.

Wetland
A lowland area (e.g., marsh, swamp, or bog) where the soil is saturated with moisture and water may cover the surface for at least a portion of the year, including the growing season. Wetlands develop unique soil types and support a large diversity of terrestrial and aquatic plants and animals. They may dry up for significant parts of the year but still provide critical habitat for plants and animals that are adapted to growing and reproducing exclusively in these areas.

Backpack electrofishing

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